HO CHI MINH NATIONAL ACADEMY OF POLITICS

HOANG THU THUY

ANALYSIS OF THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

DOCTORAL DISSERTATION ABSTRACT
MAJOR: DEVELOPMENT ECONOMICS
Code: 9310105

HANOI - 2026

The dissertation was completed at

Ho Chi Minh National Academy of Politics

Academic supervisors: **1. Dr. Ho Sy Ngoc**

2. Assoc. Prof. Dr. Phan Minh Duc

Reviewer 1:.....

Reviewer 2:.....

Reviewer 3:.....

The dissertation will be defended before the Academy-level Dissertation Evaluation Council at Ho Chi Minh National Academy of Politics

At ……. o'clock, on …… day …… month …… year ……

The dissertation can be accessed at: the National Library and Ho Chi Minh National Academy of Politics

INTRODUCTION

1. Rationale for the study

Agricultural development requires higher incomes, responsible resource use, and reduced environmental pressures. Along the Thai Binh river, farming depends heavily on land, water, hydrological conditions, and natural resources, while facing risks from pollution, saline intrusion, and extreme weather. Selecting farming systems suited to local ecological conditions and household resources is therefore essential for sustainable agricultural development.

The ragworm-organic rice production system integrates rice cultivation with the management and harvesting of natural ragworm resources and supplementary products on the same land, offering potential to increase production value and diversify income sources. However, it faces constraints related to investment capital, farming practices, production organization, marketing linkages, and environmental management. Its performance and continued viability require assessment across resource use, finance, labor, income, and the environment.

Previous studies have examined ragworm biology and ecology, production techniques, and preliminary economic outcomes. However, household-level evidence integrating these dimensions and comparing the system with intensive double-cropping rice remains limited. Further empirical evidence is needed to clarify the system's advantages, limitations, and conditions for development.

Accordingly, the dissertation, *"**Analysis of the performance of the ragworm-organic rice production system along the Thai Binh river**"* assesses the system's performance to inform development directions and measures suited to local conditions, household resources, and the need to maintain its ecological foundations.

2. Research aim and tasks

The dissertation assesses the household-level performance of the ragworm-organic rice production system along the Thai Binh River in terms of resource use, finance, labor, income, and the environment, and proposes measures to improve performance under local conditions.

The overarching research question is: How does the ragworm-organic rice production system along the Thai Binh River perform at the household level, and what measures are needed to improve its performance?

Specific research questions include: (i) What are the levels of technical, allocative, and cost efficiency, and which factors are associated with technical inefficiency? (ii) How do financial outcomes, labor use, and income differ from those of intensive double-cropping rice, and how do financial results change under assumed scenarios? (iii) How do emissions and energy use differ between the two systems, and what do soil and water samples and households' ecological perceptions indicate? (iv) What implications, development directions, and

measures do the findings suggest for local conditions?

The research tasks are to: (i) review the literature and develop the theoretical foundation; (ii) examine current production conditions; (iii) quantify efficiency and financial performance using DEA, SFA, and financial analysis; (iv) compare labor use and income; (v) assess selected environmental aspects; and (vi) synthesize the findings to propose development directions and measures through 2035, with a vision to 2045.

3. Research subject and scope

The research examines the economic, social, and environmental performance of the ragworm-organic rice production system along the Thai Binh River. Performance is assessed through input-output and cost-benefit relationships, in connection with production organization and marketing. The study area lies within Hai Phong City following administrative reorganization, covering areas formerly belonging to Hai Duong and Hai Phong. The household survey focuses on Chi Minh, Tan Minh, and Nguyen Binh Khiem communes.

Secondary data for 2020-2025 support the analysis of context and current conditions. Cross-sectional household data mainly reflect production outcomes and costs in 2025. Comparative indicators are standardized per hectare per year. Long-term financial analysis covers a ten-year period under specified cash flow assumptions. Locality names follow the new administrative units, while pre-reorganization data are aligned with corresponding geographical boundaries for aggregation and comparison.

4. Original contributions of the dissertation

Theoretical contributions: The dissertation specifies a performance assessment framework for the natural-resource-based ragworm-organic rice production system, integrating resource use, finance, labor, income, and the environment at the household level. Distinguishing calculated indicators, proxy indicators, and household perceptions clarifies the limits of the evidence and identifies complementarities and trade-offs. Combining DEA, SFA, farm accounting, and cash flow analysis broadens performance assessment, informs livelihood considerations, and systematizes conditions for expansion suited to local ecological characteristics.

Practical contributions: The dissertation provides household-level evidence and comparisons with intensive double-cropping rice, clarifying opportunities to improve resource use, financial outcomes, labor use, and selected environmental aspects. It proposes measures concerning farming practices, capital, infrastructure, linkages, and markets while maintaining ragworm habitats, prioritizing improved performance on existing farmland and conditional expansion. The findings inform farming households and public authorities and support research and teaching on organic agriculture, household economics, and

sustainable rural development.

5. Structure of the dissertation

The dissertation comprises an introduction, five main chapters, conclusions, a list of the author's publications related to the dissertation, references, and appendices.

CHAPTER 1. REVIEW OF STUDIES ON THE PERFORMANCE OF ORGANIC FARMING SYSTEMS

1.1. STUDIES ON ORGANIC FARMING SYSTEMS

1.1.1. Studies on the concept and principles of organic agriculture

Codex, IFOAM, and related authors approach organic agriculture through ecosystem management, input control, health, fairness, and responsibility. They commonly regard it as a production system rather than merely replacing chemical fertilizers with organic fertilizers. The dissertation adopts this systems approach and distinguishes practices consistent with organic principles from certification status.

1.1.2. Studies on integrated organic farming systems

Integrated organic farming combines crops, livestock, or aquaculture to share resources, recycle by-products, and diversify income. Studies identify economic, livelihood, and environmental potential, although benefits depend on system structure, ecological conditions, and management capacity. Application to the ragworm-organic rice production system requires consideration of its dependence on natural recruitment.

1.2. STUDIES ON THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM

Ragworm research has examined biological characteristics, reproduction, habitats, and field management practices. Preliminary economic studies recognize the value of producing ragworms and rice on the same land. However, household-level comparisons linking resource-use efficiency, financial performance, labor use, and environmental aspects remain limited.

1.3. STUDIES ON THE PERFORMANCE OF ORGANIC FARMING SYSTEMS

1.3.1. Studies on the multidimensional performance of organic farming systems

Studies apply the three-pillar framework, eco-efficiency, and sustainability assessment to examine economic, social, and environmental dimensions jointly. The dissertation adopts this multidimensional approach, selecting indicators suited to the ragworm-organic rice production system and household-level data while clarifying complementarities, trade-offs, and the limits of evidence for each dimension.

1.3.2. Studies on technical and resource allocation efficiency

Studies mainly use DEA and SFA to assess agricultural production efficiency. DEA measures technical efficiency and, with input prices, allocative and cost efficiency; SFA separates random noise from technical inefficiency. The dissertation applies both approaches to examine potential input savings, adjustments in resource allocation, and factors associated with inefficiency, subject to data limitations and model assumptions.

1.3.3. Studies on financial performance

Studies assess financial performance through annual revenue, cost, and profit accounting and long-term investment analysis accounting for the time value of money. The dissertation adopts both approaches to compare the profitability of the two farming systems, clarify accounting boundaries, and assess sensitivity to assumed changes in output, selling prices, and costs.

1.3.4. Studies on social performance

Studies examine the contributions of organic agriculture to employment, income, and livelihoods. Higher labor requirements may provide work opportunities but also increase costs and family labor burdens. The dissertation uses indicators of labor days, seasonal calendars, and income without equating increased labor use with stable employment or comprehensive social benefits.

1.3.5. Studies on environmental performance

Studies identify certain environmental benefits of organic agriculture, although findings depend on the functional unit, assessment boundaries, and yields. The dissertation adopts an inventory-based approach to estimate emissions and energy use per unit area, alongside soil and water sample analysis and household perceptions. It distinguishes estimates, environmental conditions at sampling sites, and changes reported by producers.

1.3.6. Studies on factors affecting organic farming performance

Studies associate organic farming performance with ecological conditions, household characteristics, resources, farming practices, markets, linkages, and policies, with effects varying across production contexts. These factor groups guide variable selection for SFA, supplemented by qualitative information to examine relationships within the available data and local conditions.

1.4. RESEARCH GAPS AND ISSUES ADDRESSED BY THE DISSERTATION

1.4.1. Research gaps

The review reveals limited research on the performance of the ragworm-organic rice production system dependent on natural resources, alongside insufficient household-level comparative data on resources, finance, and labor. Existing studies focus mainly on revenue and costs, with limited integration of input-use efficiency, long-term investment, and sensitivity analysis.

Environmental evidence remains fragmented, and the limitations of individual data sources are insufficiently clarified. Conditions for applying findings to expand the system also require further investigation.

1.4.2. Issues addressed by the dissertation

The dissertation examines the system's current status; quantifies technical, allocative, and cost efficiency; compares financial performance, labor use, and income with intensive double-cropping rice; and provides environmental evidence within the available data. It then identifies advantages, limitations, and trade-offs and proposes measures to improve performance and support conditional expansion suited to ecological conditions, household resources, production organization, and markets.

CHAPTER 2. THEORETICAL FOUNDATIONS OF ORGANIC FARMING SYSTEM PERFORMANCE AND THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM

2.1. THEORETICAL FOUNDATIONS OF ORGANIC AGRICULTURE

2.1.1. Concept of organic agriculture

Organic agriculture is a production system based on ecological principles that seeks to sustain the health of soils, ecosystems, and people. It emphasizes biodiversity, nutrient cycling, and internal resource use while restricting synthetic inputs with adverse effects. The concept encompasses management practices and relationships among production components, rather than merely a set of permitted inputs.

2.1.2. Principles and characteristics of organic agriculture

The four principles are health, ecology, fairness, and care. Key characteristics include integrated system management, soil fertility maintenance, appropriate pest management, reduced dependence on chemical inputs, process control, and traceability. Practices consistent with organic principles and certification are related but distinct considerations in identifying the study population.

2.1.3. Role of organic agriculture in sustainable development

Organic agriculture can increase product value, improve livelihoods, and reduce certain pressures on resources and the environment. Benefits depend on yields, selling prices, labor requirements, certification costs, marketing arrangements, and the ability to maintain production practices. Its contribution to sustainable development must therefore be assessed in relation to implementation conditions and trade-offs, without assuming that all organic systems outperform alternatives on every criterion.

2.1.4. Integrated organic farming systems

Integrated organic farming systems combine production activities within a shared space and ecological cycle, drawing on complementarities among crops, livestock, and aquaculture. Products, by-products, or functions of one component may provide resources for another. Performance requires system-level assessment, alongside consideration of management requirements and risks arising from input imbalances.

2.2. THEORETICAL FOUNDATIONS OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM

2.2.1. Concept of the ragworm-organic rice production system

The ragworm-organic rice production system combines rice cultivation following organic principles with the management and harvesting of natural ragworm resources in tidally influenced fields. This semi-natural integrated system may generate additional income from crabs, other aquatic species, and supplementary crops. Maintaining ragworm habitats is essential to the functioning of the entire system.

2.2.2. Criteria for identifying households participating in the ragworm-organic rice production system

Participating households directly combine ragworm and rice production, manage land and water, and use inputs consistent with organic principles. The dissertation distinguishes farming practices from certification status. Its findings represent households whose practices were documented through the survey, without assuming that the entire sample was organically certified.

2.2.3. Characteristics of the ragworm-organic rice production system

The system draws on complementarities among rice, ragworms, and field organisms; uses tidal water and natural resources; restricts chemical inputs; and produces multiple products on the same land. These characteristics offer potential to increase production value and stagger work across seasons, while making production highly dependent on environmental quality, weather, natural ragworm availability, and water management skills.

2.2.4. Conditions for establishing the ragworm-organic rice production system

Required conditions include suitable soil and substrate; appropriate water regimes, salinity, and natural ragworm availability; water supply and drainage capacity; capital for field improvement; labor and experience; production organization; and markets. Increased investment alone cannot compensate for the absence of essential ecological conditions. Infrastructure must support water management suited to both ragworms and rice.

2.2.5. Factors affecting the performance of the ragworm-organic rice production system

Performance is influenced by ecological conditions; household resources and management capacity; farming practices and input quantities and

combinations; output and input prices; linkages; and policies. Constraints involving capital, labor, information, and risk may prevent households from choosing the least-cost input combination. Measures must therefore reflect practical conditions rather than rely solely on efficiency scores.

2.3. PERFORMANCE DIMENSIONS OF ORGANIC FARMING SYSTEMS

2.3.1. Concept of performance

Performance reflects the extent to which objectives are achieved in relation to resources used and outcomes generated. Production analysis must distinguish output, revenue, and profit levels from input-use efficiency. High production value does not necessarily imply cost minimization, while high financial profits may not fully reflect opportunity costs and non-market effects. This distinction guides indicator selection and the limits of the dissertation's conclusions.

2.3.2. Dimensions for assessing organic farming system performance

Technical efficiency reflects the ability to produce outputs with given inputs; allocative efficiency concerns input combinations at prevailing prices; and cost efficiency combines both dimensions. Financial performance reflects profitability within defined accounting boundaries. The social dimension focuses on labor use, seasonality, and income. The environmental dimension covers resources, soil and water quality, emissions, energy use, and ecological perceptions.

2.3.3. Relationships among performance dimensions of organic farming systems

Performance dimensions may involve complementarities or trade-offs. Higher production value per unit area may require more capital and labor; restricting chemicals may reduce certain environmental pressures while increasing management requirements. Indicators of different types should not be aggregated into a conclusion of overall performance without justified weights and comparison benchmarks.

2.4. THEORETICAL FOUNDATIONS OF EFFICIENCY AND SUSTAINABLE DEVELOPMENT IN AGRICULTURE

2.4.1. Agricultural production efficiency theory

Production theory provides the foundation for analyzing input-output relationships and efficiency frontiers. The dissertation applies Farrell's approach to distinguish technical efficiency (TE), allocative efficiency (AE), and cost efficiency (CE), where CE = TE x AE at the household level. CE represents cost efficiency within the specified model.

2.4.2. Multidimensional performance approach

This approach considers economic outcomes alongside labor, livelihoods, and the environment, interpreting findings according to the available evidence. It

does not infer overall superiority from a single indicator.

2.4.3. Sustainable livelihoods theory and the livelihood transformation approach

The livelihoods framework examines assets, activities, risks, and adaptive capacity. It supports the interpretation of production choices, labor use, and income sources; the dissertation does not measure a composite livelihood index.

2.4.4. Theory of development based on local resources

Development based on local resources emphasizes distinctive local advantages and organizational capacity. It links the value of the ragworm-organic rice production system to resource conservation, local knowledge, and markets.

2.4.5. Sustainable agriculture theory

Sustainable agriculture considers current performance in relation to resource maintenance and future production capacity. This theory guides implications for management, monitoring, and conditional expansion, without replacing empirical evidence of long-term sustainability.

Agricultural production efficiency theory underpins input-output analysis, complemented by a multidimensional approach to assess financial performance, labor use, income, and environmental aspects at the household level. Sustainable livelihoods, local-resource-based development, and sustainable agriculture theories support the interpretation of findings and the formulation of development implications consistent with household resources, ecological conditions, and the scope of the dissertation's evidence.

CHAPTER 3.
ANALYTICAL FRAMEWORK AND RESEARCH METHODS

3.1. ANALYTICAL FRAMEWORK FOR ASSESSING THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM

The framework links ecological, socioeconomic, and institutional conditions to household resources, production activities, outputs, and outcomes. DEA and SFA assess resource-use efficiency; farm accounting and cash flow analysis assess financial performance; labor use and income provide livelihood perspectives; and inventories and surveys provide environmental evidence. The findings are synthesized to identify advantages, limitations, trade-offs, and conditions for implementing proposed measures.

3.2. INDICATORS FOR ASSESSING THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM

3.2.1. Basis for indicator selection and classification

Indicators are selected according to research objectives, theoretical foundations, system characteristics, and data availability. Direct measures, proxy

indicators, and household perceptions are distinguished. Data sources, units, and interpretive boundaries are specified to avoid treating evidence with different levels of certainty as equivalent.

3.2.2. Technical efficiency and resource-use indicators

TE measures technical distance from the frontier; AE reflects input combinations given input prices; and CE represents the ratio of minimum to observed costs. CE = TE x AE for each household, but mean CE does not necessarily equal mean TE multiplied by mean AE. Efficiency scores are conditional on the selected variables, technology, and prices.

3.2.3. Financial performance indicators

Total revenue (TR) is the total value of products. Cash costs (C) comprise intermediate costs and hired labor costs; total costs are TC = C + D, where D denotes depreciation. Value added is VA = TR - IC, where IC denotes intermediate costs; the pre-depreciation surplus is S = TR - C; and financial profit is Pi = TR - C - D. Financial ratios include Pi/TC and TR/TC. Long-term cash flow indicators include net benefits (NB), net present value (NPV), equivalent annual annuity (EAA), benefit-cost ratio (BCR), internal rate of return (IRR), and payback period.

3.2.4. Labor-use and income indicators

Indicators include total labor days per hectare per year, seasonal work distribution, and income from the system, primarily represented by profit after depreciation. Labor days reflect labor requirements. Profit before deducting family labor costs is not equivalent to net income after all opportunity costs.

3.2.5. Environmental performance indicators

Environmental aspects are assessed using estimated greenhouse gas emissions and energy use, soil and water sample results, and household perceptions. Each indicator has specific assessment, spatial, and temporal limitations.

3.3. DATA COLLECTION METHODS

3.3.1. Secondary data collection

Secondary data include scientific publications, statistical reports, production records, official documents, and information from public authorities and cooperatives. These support the literature review, analytical framework, and description of production conditions and trends. Data spanning administrative boundary changes are assigned to corresponding locations and periods and distinguished from cross-sectional survey data.

3.3.2. Household survey

Chi Minh, Tan Minh, and Nguyen Binh Khiem communes were purposively selected. Eligible ragworm-organic rice households directly engaged in production, had participated for at least three years, and could provide relevant

information. This criterion identifies experienced households but does not establish stable production conditions. The sample does not fully represent recent adopters or households that discontinued production.

An indicative sample-size calculation based on 2,600 households and a margin of error of 0.1 yielded approximately 97 households. The study expanded the sample to 180 ragworm-organic rice households. The comparison group comprised 180 intensive double-cropping rice households in the same locations, giving 360 households in total. Each farming system included 90 households in Chi Minh, 60 in Tan Minh, and 30 in Nguyen Binh Khiem. Households were randomly selected from eligible lists.

Questionnaires were checked for completeness and consistency, entered and processed in Excel, and cross-checked against interviews and secondary sources. Welch's tests were used for quantitative variables and chi-square tests for categorical variables. The groups differed in experience, farm area, and household labor availability; comparisons were therefore interpreted descriptively.

3.3.3. Key informant interviews

The study interviewed 18 informants: 12 experienced farming households, four public officials or cooperative representatives, and two business representatives. Information on farming practices, markets, opportunities, and constraints was recorded, organized thematically, and cross-checked across sources to support interpretation of quantitative findings.

3.4. ANALYTICAL METHODS

3.4.1. Analysis of technical efficiency and resource use

Input-oriented DEA under variable returns to scale (VRS) was conducted using DEAP 2.1. The five inputs were land area, labor, tillage, fertilizers, and ragworm feed; outputs were ragworm and rice quantities. Input prices were incorporated to estimate minimum costs, TE, AE, and CE.

DEA sensitivity analysis covered ten scenarios: replacing VRS with constant returns to scale (CRS), excluding land area, and separately increasing or decreasing each positive input price by 20%. Comparisons used means, differences, absolute deviations, and Spearman's rank correlations.

A one-step Cobb-Douglas SFA model was estimated in R, combining a production function with an inefficiency equation. Household characteristics included education, experience, linkages, and market conditions. SFA provided complementary evidence for comparison; its results depend on the output measure, functional form, and assumed distributions.

3.4.2. Financial performance analysis

Annual farm accounting and long-term investment analysis were combined to compare the two systems, with annual indicators standardized per hectare per

year. Indicators included revenue, costs, value added, profit after depreciation, and financial ratios. Ten-year cash flow analysis used NPV, EAA, BCR, IRR, and payback period at an annual discount rate of 6.5%. The baseline included hired labor costs but excluded family labor and the opportunity costs of land and own capital.

Sensitivity analysis examined assumed changes in output or selling prices, investment and operating costs, and scenarios with and without family labor costs.

3.4.3. Analysis of labor use and income

Descriptive statistics compared total labor days, work calendars, and profit after depreciation. Revenue and the revenue-cash cost surplus served as supplementary indicators. Interviews supported interpretation of seasonality, labor allocation, and employment opportunities. Causal effects and stable employment were not quantified.

3.4.4. Analysis of environmental aspects

Emissions and energy inventories were calculated by summing input quantities multiplied by their respective coefficients, expressed per hectare per year. The assessment covered selected seed, material, supplementary feed, lime, fuel, and electricity inputs. Three soil samples from the 0-20 cm layer and three water samples were collected across the three communes on 20 December 2025. Sample results and household perceptions provide descriptive evidence; they neither represent the entire region nor establish changes attributable to the farming system.

CHAPTER 4. CURRENT PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

4.1. PRODUCTION CONDITIONS FOR THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

4.1.1. Natural conditions

The study area is influenced by the Thai Binh River's flows and tides, creating intermittently inundated habitats with alluvial soils and fresh-to-brackish water. Tidal exchange brings natural ragworm recruits, other organisms, and nutrients into fields, while requiring control of water levels, salinity, and incoming water quality. Weather, storms, floods, droughts, and hydrological changes may affect production outcomes.

4.1.2. Socioeconomic conditions

Labor availability, experience in ragworm harvesting, and market demand support the system's development. Cooperatives, enterprises, and organic agriculture policies facilitate production organization, certification, and trade. However, households operate on a small scale and differ in access to capital,

water management infrastructure, storage facilities, and services. These factors require consideration when comparing performance.

4.2. CURRENT STATUS OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

4.2.1. Formation and transition of production practices

The system evolved from harvesting natural ragworms to combined ragworm-rice production, followed by field management oriented toward organic practices and markets. Farmers have gained greater control over field improvement, water regulation, input selection, and harvesting, while ragworm recruitment and population regeneration remain dependent on natural processes. Transition requires infrastructure investment and adaptation time, beyond changes in varieties or fertilizers.

4.2.2. Spatial distribution of production

The ragworm-organic rice farming area along the Thai Binh River covers approximately 1,020 ha, mainly on alluvial land and riverside fields with suitable soil, water, and hydrological conditions. Production extends along the upper and lower sections of the studied river reach, concentrated in Chi Minh, Vinh Thuan, Tien Lang, Tan Minh, Vinh Bao, and Nguyen Binh Khiem communes in Hai Phong City.

Production areas have expanded, with some concentrations emerging, although their distribution remains uneven across localities. The scale and development potential of the system depend on natural ragworm availability, soil and water quality, water regulation capacity, and production organization.

4.2.3. Processing, branding, and marketing

Processing, storage, and branding have gradually developed, helping increase the value of ragworm and rice products and expand markets. Products are marketed through traders, cooperatives, enterprises, and direct sales, with growing attention to certification, traceability, and promotion. However, limited storage and processing capacity, weak marketing linkages, and seasonal price fluctuations require coordinated improvements in quality, branding, and market organization.

4.2.4. Production and marketing linkages

Linkages connect households with cooperatives, enterprises, and support organizations in input supply, technical guidance, and product marketing. Participation remains limited, and many relationships are informal, lacking contracts and binding commitments. Strengthening cooperatives' coordinating role and improving collaboration and the sharing of benefits and risks are therefore necessary.

4.2.5. Advantages and constraints of the ragworm-organic rice production system

Key advantages include distinctive habitats, high-value products, local experience, labor availability, and policy support for ecological agriculture. Combining multiple products offers potential to increase production value per unit area and diversify income sources.

Constraints include capital requirements for field improvement, limited revenue during the initial period, ecological management requirements, rice yields, pollution, and hydrological risks. Dispersed production, limited storage, price fluctuations, and insufficient coordination in market development and certification increase management pressures. Maintaining these advantages therefore requires coordinated improvements in farming practices, infrastructure, linkages, and water protection; area expansion alone does not ensure better performance.

4.3. CURRENT PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

4.3.1. Technical efficiency and resource use

Input-oriented DEA under VRS for 180 households indicates relatively high technical efficiency, with scope to improve allocative and cost efficiency. The statistics describe the distribution of household efficiency scores within the study's reference set.

DEA estimates of technical, allocative, and cost efficiency

Indicator	Mean	Median	Standard deviation
TE	0.854	0.849	0.093
AE	0.817	0.806	0.100
CE	0.698	0.686	0.121

Source: Calculations from household survey data

Twenty-three households achieved TE = 1 (12.8%); 54 had TE below 0.8 and 11 below 0.7. The average potential proportional input reduction was approximately 14.61%, holding outputs constant relative to the reference frontier. TE = 1 does not necessarily imply the absence of input-specific slacks or establish maximum productivity under all conditions.

Mean AE was 0.817; six households achieved 1, 82 scored below 0.8, and one below 0.6. Low AE suggests scope to adjust input combinations given prices, subject to constraints involving capital, input access, labor, and risk management. Assigning a zero price to land excludes the opportunity cost of owned land.

Mean CE was 0.698, ranging from 0.466 to 1.000; six households achieved 1, 151 scored below 0.8, and 37 below 0.6. The average potential cost reduction was approximately 30.15% within the priced input set. This is the mean of household-level reduction rates, rather than the potential reduction in aggregate sample costs or a uniformly applicable target.

Sensitivity analysis showed that separately changing each positive input

price by ±20% left mean TE unchanged at 0.854. Mean AE ranged from 0.815 to 0.819 and CE from 0.697 to 0.700, with rank correlations for AE and CE of approximately 0.996 or higher. Excluding land yielded TE of 0.846, AE of 0.825, and CE of 0.698. Under constant returns to scale (CRS), the respective means fell to 0.805, 0.380, and 0.318. The results were therefore relatively stable under the price scenarios examined but sensitive to the returns-to-scale assumption.

SFA yielded mean TE of approximately 0.931. Higher SFA scores than DEA scores reflect differences in model specification, reference frontiers, and treatment of statistical noise. The tillage coefficient was 0.6765 ($p = 0.05343$), indicating a positive association with output at the 10% significance level. The feed coefficient was -0.0643 ($p = 0.03013$), indicating a negative association at the 5% level. This negative association does not establish that increased feeding reduces output; it may reflect field conditions, input quality, application practices, endogeneity, or measurement error. Land area, labor, and fertilizer coefficients were not statistically significant.

Education, experience, linkages, and market variables all had negative coefficients in the inefficiency equation, but none was significant at the 10% level. Evidence is therefore insufficient to establish their effects in the sample. The estimate of gamma ≈ 1 is interpreted cautiously in light of the estimation assumptions and limitations of model testing.

4.3.2. Annual financial performance

Average revenue from the ragworm-organic rice production system was VND 321,778 thousand/ha/year, comprising VND 233,578 thousand from ragworms, VND 60,422 thousand from paddy rice, and VND 27,778 thousand from other sources. Ragworms accounted for approximately 72.6% of total revenue. Revenue from intensive double-cropping rice was VND 86,800 thousand/ha/year.

Initial investment in the ragworm-organic rice production system was VND 132,198 thousand/ha. Major annual costs included organic fertilizers, microbial fertilizers, feed, tillage, and hired labor. Profit after depreciation was approximately 6.02 times that of intensive double-cropping rice. Each VND of total costs generated VND 3.65 in revenue and VND 2.65 in financial profit. These results exclude family labor costs and the opportunity costs of land and own capital.

Selected financial indicators of the two farming systems

Indicator (thousand VND/ha/year, except ratios)	Ragworm-organic ric	Intensive double-cropping rice
Cash costs	79,884	47,988
Total costs (TC), including depreciation	88,104	47,988

Value added	254,494	42,557
Financial profit (Pi)	233,674	38,812
Pi/TC (ratio)	2.65	0.81

Source: Calculations from household survey data

Financial outcomes varied considerably across households. For the ragworm-organic rice production system, median revenue was VND 314,081 thousand, with a standard deviation of VND 138,892 thousand; median profit was VND 218,311 thousand, with a standard deviation of VND 121,452 thousand. Corresponding figures for intensive double-cropping rice were VND 82,486 thousand and VND 66,921 thousand for revenue, and VND 33,238 thousand and VND 57,898 thousand for profit.

4.3.3. Social performance: labor use and income

The ragworm-organic rice production system required 272 labor days/ha/year, compared with 220 for intensive double-cropping rice. Labor was required for rice cultivation, water management, habitat monitoring, and ragworm and crab harvesting. Rice-related work was concentrated from the beginning of the year through May-June, while ragworm management and harvesting were prominent during September-December, with supplementary activities between these periods. This pattern suggests opportunities to stagger work across seasons and use otherwise idle labor.

Production income was assessed primarily through profit after depreciation: VND 233.674 million/ha/year, compared with VND 38.812 million. Employment opportunities in input supply, processing, storage, and marketing were discussed as potential implications of the system.

4.3.4. Environmental performance

For the selected inputs and emission sources, comparisons of corresponding lower and upper bounds showed that intensive double-cropping rice generated 1.33-1.52 times the emissions and used 1.58-1.93 times the energy of the ragworm-organic rice production system. The latter had approximately 24.7-34.0% lower emissions and 36.7-48.1% lower energy use. Differences in input composition partly explain these gaps: the ragworm-organic rice production system used no chemical fertilizers or synthetic pesticides, although organic fertilizers, feed, and lime still contributed substantially to emissions and energy use.

The analyzed soil and water samples met the applicable safety criteria for the parameters assessed. None of the tested pesticide compounds was detected in soil samples within the analytical methods' detection limits.

The survey found that 55% of households perceived improved soil fertility, 41% reported more friable soil, and 81% reported increased soil organisms. Regarding field organisms, 46% reported a substantial increase and 39% an

increase. Management of water, organic fertilizers, and feed should incorporate monitoring of nutrients, eutrophication risks, and ragworm habitats.

4.4. LONG-TERM FINANCIAL PERFORMANCE AND ROBUSTNESS TO CHANGES

4.4.1. Long-term financial performance

Of the initial investment of VND 132.198 million/ha, long-lived assets accounted for VND 82.198 million. Depreciation over ten years was assumed, equivalent to VND 8.220 million/year. No revenue was assumed in Year 1, rice revenue in Year 2, and reference revenue from Year 3. From Year 4, revenue and cash costs increased by 3% annually.

At a discount rate of 6.5%, the ragworm-organic rice production system yielded an NPV of VND 1,223,204 thousand/ha, an EAA of VND 170,153 thousand/ha/year, a BCR of 2.7, and an IRR of 56%. Intensive double-cropping rice yielded an NPV of VND 315,000 thousand/ha, an EAA of VND 43,818 thousand/ha/year, and a BCR of 1.8. Under the study assumptions, cash flow analysis indicated long-term profitability and higher financial indicators for the ragworm-organic rice production system.

Its undiscounted and discounted payback periods were approximately 2.88 and 3.03 years, respectively. These returns over the investment period were accompanied by financing pressures during the initial negative cash flow period.

4.4.2. Sensitivity analysis of changes and financial risks

Under a 50% reduction in yield or selling prices, the ragworm-organic rice production system retained a positive NPV; a 70% reduction resulted in a negative NPV. With investment and operating costs increasing by 80%, its NPV remained positive, while intensive double-cropping rice approached the financial viability threshold. When family labor costs were included, NPV fell to VND 658,175 thousand for the ragworm-organic rice production system and -VND 176,330 thousand for intensive double-cropping rice, according to the dissertation's scenario table.

4.5. ASSESSMENT OF THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

4.5.1. Main achievements and strengths

The ragworm-organic rice production system generated higher revenue, value added, and profit per unit area than intensive double-cropping rice within the accounting boundaries. Average technical efficiency was relatively high, while allocative and cost efficiency results indicated scope for further improvements in resource use. Combined production activities created a staggered work calendar, suggesting opportunities for local labor allocation. Estimated greenhouse gas emissions and energy use were lower than those of the

comparison system within the inventory boundaries, providing additional evidence for considering its environmental advantages.

4.5.2. Remaining limitations

The system required substantial initial investment and relatively high labor inputs, while revenue remained limited during the initial transition period. Production depended on natural ragworm resources, water quality, and hydrological conditions, with revenue concentrated mainly in ragworms. Production and marketing linkages remained limited, while storage capacity, certification implementation, and cost management varied across households.

4.5.3. Causes of the limitations

These limitations were associated with household capital, labor, and management capacity; fragmented farmland; and insufficiently coordinated water management infrastructure, storage services, and market linkages. Accessing and implementing support remained difficult, while variations in hydrology, source water quality, and natural ragworm availability increased production risks.

4.6. Implications for rural economic development based on the ragworm-organic rice production system

4.6.1. Strengthening sustainable livelihoods and income stability

Higher income per unit area and a staggered work calendar suggest potential for developing the system as a livelihood option in suitable locations. Maintaining these advantages requires appropriate capital and labor management, income diversification, and contingency planning for ecological and market risks.

4.6.2. Promoting riverine economic development based on distinctive ecological advantages

Natural ragworm resources, riverside alluvial land, and local production knowledge provide a foundation for distinctive products and associated storage, processing, and marketing activities. Developing these advantages requires resource conservation, stronger linkages among households, cooperatives, and enterprises, and improved market organization.

4.6.3. Informing a transition toward higher-value and environmentally conscious production

The findings suggest a transition that emphasizes the combined value of the farming system, appropriate input use, and joint consideration of profitability, labor requirements, and environmental aspects. Priorities include improving performance on existing farmland, maintaining ragworm habitats, and strengthening soil and water management. Additional investment or area expansion should be assessed against ecological conditions, household resources, and market capacity through pilot implementation and evaluation before wider

adoption.

CHAPTER 5. DIRECTIONS AND MEASURES TO IMPROVE THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER

5.1. CONTEXT AFFECTING THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER THROUGH 2035

5.1.1. International context

Growing consumer attention to quality, traceability, and the environment creates opportunities for ecological products while increasing requirements to demonstrate compliance with production practices. The green transition, technology, and market linkages support improved management, while climate change, competition, and trade standards increase risks. International opportunities translate into outcomes only when production areas meet quality, storage, and supply requirements.

5.1.2. Domestic context

Policy directions promoting organic and ecological agriculture, the circular economy, and digital transformation provide a supportive foundation. Domestic markets and local products offer potential, but urbanization, pressures on land and water, capital constraints, and household capacity pose challenges. Policy instruments must specify implementing authority, resources, eligibility criteria, and arrangements for sustaining outcomes after support ends.

5.2. DEVELOPMENT DIRECTIONS FOR THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER THROUGH 2035, WITH A VISION TO 2045

5.2.1. Development principles and directions

Development should build on ecological advantages and local resources; jointly consider economic performance, labor requirements, and environmental aspects; and strengthen the roles of households, cooperatives, and enterprises. Priorities include improving performance on existing farmland, managing water and input quality, and strengthening marketing linkages. Development through 2035, with a vision to 2045, must remain conditional on capital availability, infrastructure, and market demand.

5.2.2. Conditions and scope for expansion

Six screening criteria groups cover: hydrology, salinity, and natural ragworm availability; soil and water quality and pollution risks; farm scale and land coordination; capital and water management infrastructure; coordinating organizations and certification; and markets, storage, and processing. Each group is assessed as meeting, conditionally meeting, or not meeting requirements.

Expansion should not proceed where essential ecological conditions are absent or pollution remains uncontrolled. Specific thresholds require further monitoring and validation; expansion should involve pilot implementation and periodic evaluation.

5.3. MEASURES TO IMPROVE THE PERFORMANCE OF THE RAGWORM-ORGANIC RICE PRODUCTION SYSTEM ALONG THE THAI BINH RIVER THROUGH 2035, WITH A VISION TO 2045

5.3.1. Measures to improve technical efficiency and resource allocation

Training and technology transfer should focus on field ecosystem management, including substrate improvement, water regulation, habitat monitoring, and appropriate use of organic fertilizers and feed. Guidance should reflect field conditions and household capacity, combining demonstration sites, experience sharing, and field-based advice.

Cost management should draw on records of inputs, labor, output, prices, and transaction dates. DEA results help identify households and inputs requiring review; average reduction rates should not be applied uniformly. Staggered labor allocation, shared services, and appropriate mechanization may reduce workloads while preserving ragworm habitats.

5.3.2. Measures to reduce financial barriers and production risks

Existing credit schemes should be linked to investment plans and payback cycles, with loan terms and repayment schedules suited to the transition period, subject to applicable policies and credit assessment. Households and cooperatives should prepare cash flow plans, counterpart funding, and repayment capacity. Local authorities should facilitate information, documentation, and connections without replacing lenders' credit decisions.

Financial support should target infrastructure, transition, certification, and value chains under approved programs and budgets. Insurance requires risk data, loss assessment capacity, and voluntary participation, with piloting before expansion. Financial reserves, water quality and climate warnings, and marketing linkages should be combined to reduce losses.

5.3.3. Measures for production organization and ragworm-organic rice value chain linkages along the Thai Binh River

Cooperatives should coordinate standardized practices, recordkeeping, and internal quality control. Certification should cover operations meeting relevant requirements and market needs. Traceability should rely on verifiable records linking households, plots, inputs, harvests, and product batches. Storage and processing should develop in line with output volumes and capital availability.

Immediate priorities are production practices and marketing linkages; medium-term priorities are certification, traceability, and storage services; longer-term priorities are processing and market expansion based on

demonstrated performance. Contracts should specify quality, prices, delivery, payment, and remedies for breaches. Branding must be supported by supply capacity, distribution, and benefit sharing.

5.3.4. Environmental and sustainable development measures

Production areas should be managed within the basin's ecological context, coordinating water supply, drainage, and pollution control. Measures should protect habitats and natural ragworm resources, monitor soil and water, and improve nutrient and feed management, including guidance on composting, application rates, and timing. Monitoring should cover seasonal and hydrological variations.

Community communication should link responsibility for water protection to livelihood benefits. Climate adaptation should combine early warnings, operational adjustments, contingency plans, and coordination across localities. Environmental measures must maintain the ecological foundations of production rather than merely satisfy certification formalities.

5.3.5. Conditions for implementation

Implementation requires coordination among public authorities, technical agencies, research institutions, enterprises, cooperatives, and households, with clearly assigned responsibilities, funding sources, timelines, and monitoring indicators. Public funding, credit, and counterpart contributions should be matched to appropriate activities. Outcomes, ongoing costs, and risks should be assessed before expansion.

5.4. RECOMMENDATIONS

5.4.1. For the Government and central authorities

Improve support policies for integrated organic farming, distinguishing credit from budgetary funding. Specify eligible beneficiaries, expenditures, support periods, and counterpart contributions. Provide appropriate guidance on quality and certification, shared infrastructure, risk data, and pilot evaluation.

5.4.2. For local authorities along the Thai Binh river

Select production areas according to soil, water, hydrology, resources, and market access, and publish eligibility criteria. Each support measure should specify estimated costs, funding sources, coordinating bodies, and responsibilities for operation, maintenance, and monitoring. Prioritize performance improvements on existing farmland, water regulation, and pollution control.

5.4.3. For cooperatives, enterprises, and production linkage organizations

Cooperatives should standardize practices, control quality, and manage records and data. Enterprises should communicate market requirements and fulfill contracts. Service, certification, and storage costs should be transparent.

Responsibilities should reflect each party's role in transactions, alongside continued field-based training.

5.4.4. For ragworm-organic rice farming households

Households should invest according to their capital, labor, and field conditions, and record revenue, costs, and family labor. They should follow production protocols, provide accurate information, fulfill linkage commitments, and plan for counterpart contributions, loan repayments, ongoing costs, and risk contingencies.

CONCLUSIONS

1. Main findings

The dissertation synthesizes theoretical foundations and develops a framework for assessing the performance of the ragworm-organic rice production system along the Thai Binh River across resource use, finance, labor, income, and the environment. It distinguishes evidence sources and interpretive limits for each indicator group.

The findings clarify the system's reliance on natural ragworm resources, ecological conditions, and local experience. The system can combine multiple products on the same land but faces constraints involving capital, labor, storage, and marketing linkages.

DEA and SFA indicate relatively high average technical efficiency, while DEA identifies scope to improve allocative and cost efficiency. Education, experience, linkages, and market variables in SFA are not statistically significant. The ragworm-organic rice production system achieves better financial outcomes than intensive double-cropping rice within the accounting boundaries. Long-term profitability depends on the assumptions used and declines when family labor costs are included.

The system requires more labor days and involves staggered seasonal activities, suggesting opportunities for local work allocation. Income per unit area is higher, although revenue remains concentrated in ragworms. Estimated emissions and energy use are lower within the inventory boundaries. Soil and water samples and household perceptions provide complementary environmental evidence but do not establish region-wide improvements attributable to the system.

The dissertation accordingly proposes four groups of measures: improving technical efficiency and resource allocation; reducing financial barriers and risks; strengthening production organization and value chain linkages; and enhancing environmental management and sustainable development. These measures prioritize improved performance on existing farmland, clearly assigned stakeholder responsibilities, and conditional expansion.

2. Limitations

The study compares the system only with intensive double-cropping rice, uses cross-sectional data, and surveys households currently maintaining production. It therefore does not fully capture changes over time, households that discontinued the system, or causal relationships. Individual households' organic certification status has not been fully verified.

DEA and SFA results depend on the data, variable selection, and assumptions, with limited alternative specification and robustness checks. Financial analysis relies on assumed cash flows and does not fully capture simultaneous changes or all opportunity costs. Environmental estimates do not constitute a full life cycle assessment. Small numbers of soil and water samples and reliance on self-reported perceptions limit generalizability.

Future research should broaden comparisons, include households that discontinued production, develop panel data, examine alternative specifications and joint risk scenarios, and incorporate seasonal environmental monitoring.

LIST OF THE AUTHOR'S PUBLICATIONS RELATED TO THE DISSERTATION

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2. Hoang Thu Thuy (2025), The Pioneering Role of the Organic Ragworm-Rice Production Model in Vietnam's Current Sustainable Agricultural Development Strategy, *Finance Journal*, ISSN 2615-8973, pp. 216-219.

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