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Cluster analysis of organic rice production systems and management patterns: Case study of Sathing Phra Peninsula, Southern Thailand

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Abstract

Background and Objective: The transformation of traditional rice farming into sustainable organic systems presents significant challenges, particularly in regions with unique geographical contexts. In Southern Thailand's Sathing Phra Peninsula, organic rice production covers only 0.31% of the total cultivation area, yet exhibits distinctive adaptation patterns. This study aimed to analyze the heterogeneity of organic rice production systems in the peninsula through cluster analysis, focusing on identifying and characterizing different farmer typologies based on their production practices, resource management, and certification patterns.

Methodology: The study examined 47 certified organic rice farmers across four districts during the 2022/23 growing season. Data collection included semi-structured interviews, field observations, and focus group discussions. Eight standardized variables were analyzed using hierarchical clustering methods: certification patterns, cultivation frequency, farming methods, water source utilization, yield levels, farmland area, seed management, and labor utilization. Statistical analysis employed Ward's method with Euclidean distance, followed by one-way ANOVA.

Main Results: Three distinct farmer groups were identified: 1) commercial organic farmers (21.28%), characterized by larger cultivation areas (>11.98 rai) and higher yields (>500 kg/rai), 2) integrated organic farmers (27.66%), combining traditional methods with modern technology, and 3) traditional organic farmers (51.15%), primarily smallholders following conventional practices. Statistical analysis revealed significant differences ($P < 0.05$) across all variables, with yield variations showing the highest variance ($F = 68.44$). Price premiums varied by 15–20% between groups, reflecting market access disparities.

Conclusions: Three distinct farmer clusters were identified with significant productivity variations ($P < 0.05$). Commercial organic farmers achieved the highest yields (>500 kg/rai) on larger farms, while traditional smallholders (51.15%) maintained lower productivity (300–400 kg/rai). Infrastructure access and water management proved critical determinants of organic rice farming success, requiring differentiated support strategies for sustainable development.

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INTRODUCTION

The transformation of traditional rice farming landscapes into sustainable organic systems represents one of the most significant challenges in modern agriculture. While organic rice production has emerged as a promising solution to environmental and market demands globally (Babajani *et al.*, 2023), its development patterns vary significantly across different geographical contexts. The Sathing Phra Peninsula in Southern Thailand presents a fascinating case study of this agricultural evolution, where, despite organic practices covering only 0.31% of the total rice cultivation area, unique farming adaptations have emerged from the interplay of traditional knowledge, ecological conditions, and institutional support systems.

Nestled between the Gulf of Thailand and Songkhla Lake, the peninsula's distinctive geography creates specific agro-ecological conditions that have shaped local farming practices and management strategies for generations (Pramanik *et al.*, 1987; La-ongsiriwong, 2017). This geographical uniqueness sets it apart from Thailand's major rice-growing regions, particularly the Northeast, where organic rice farming has flourished through contract farming and NGO support (Puapongsakorn, 2010; Chitchop *et al.*, 2014). The Sathing Phra Peninsula stands as the only area in Southern Thailand with commercial organic rice production that maintains year-round production and distribution, and was the first in the southern region to receive Organic Thailand certification during the certification period (T3). In contrast, the southern region's organic rice sector has evolved primarily through government initiatives and local farmer groups, resulting in distinct production patterns and management approaches.

Recent research has identified key factors influencing farmers' decisions to adopt organic rice production in Thailand. Incentives for entering organic rice production include government and private sector promotion policies, environmental concerns, replacement of plant prices, and prices of production factors. Causal factors for entry into certified organic production encompass farmers' determination and commitment, government promotion, community leaders' influence, and support from government projects. However, barriers to certification adoption persist, including difficulties in the assessment system, highlighting the complex interplay of motivational and structural factors that influence organic farming transitions (Bunsong *et al.*, 2024).

As Thailand seeks to diversify its organic rice production beyond traditional strongholds, understanding these regional variations becomes crucial (Rattanasuteerakul and Thapa, 2012). This study employs cluster analysis to examine the heterogeneity of organic rice production systems in the Sathing Phra Peninsula, focusing on identifying and characterizing different farmer typologies based on their production practices, resource management, and certification patterns. The findings aim to address the critical gap in region-specific understanding highlighted by recent agricultural development studies (Kramol *et al.*, 2015), ultimately contributing to more nuanced and locally adapted policies for promoting organic rice production in Southern Thailand's unique coastal contexts.

MATERIALS AND METHODS

Study Area and Sample Selection

This study was conducted in the Sathing Phra Peninsula of Southern Thailand during the 2022/23 growing season (November 2023 to November 2024), encompassing four districts: Ranot, Singhanakhon, Sathing Phra, and Krasae Sin. The region was selected for its unique geographical characteristics, positioned as a narrow strip of land between the Gulf of Thailand and Songkhla Lake, creating distinct agro-ecological conditions that influence rice cultivation practices and water management strategies.

Data Collection and Sampling

This study employed a mixed-methods approach, integrating both quantitative and qualitative techniques to investigate rice farming practices during the 2022/23 growing season, with a particular on organic farming systems. Secondary data were sourced from two official government databases. The first was the Organic Agriculture Promotion Project certification registry provided by the Rice Department (2023), which documented 37 certified organic rice farmers who had received Organic Thailand certification, cultivating a total area of 232 rai. The second source was the Major Rice Farmer Registration database maintained by the Department of Agricultural Extension (2023), which recorded 7,072 farming households engaged in rice cultivation, covering 75,329.48 rai across all districts. These datasets were analyzed to identify overarching production patterns, including total cultivation area, the proportion of organic farming, household distribution, and farming practices across all districts.

For primary data collection, 47 organic rice farmers were selected using a combination of snowball and purposive sampling until data saturation was achieved. Key informants included 21 farmers from Singhanakhon district, 14 from Krasae Sin district, and 12 from Ranot district. All participants met the selection criteria of maintaining consistent organic farming practices and having previously obtained organic certification. Specifically, informants were required to be organic rice producers who had received at least one organic certification standard. Among the participants, 31 farmers currently held organic certifications, all certified under the Organic Thailand standard, with one farmer additionally certified under the Participatory Guarantee System (PGS). The remaining 16 participants had previously held organic certifications: 15 under the Organic Thailand standard and one under the PGS.

Data collection was conducted through in-depth interviews and field observations. The interviews explored production aspects, household socio-economic factors, and farming practices, covering quantitative data such as cultivation area, yield levels, resource utilization patterns, income sources, and market access. Additionally, qualitative aspects were explored, including farmers' motivations, challenges, adaptive strategies, traditional farming knowledge, and community relationships, providing crucial context for understanding farming approaches beyond economic indicators.

Field observations were carried out using both participant and non-participant observation techniques. Researchers documented observations through field notes, photographs (with participant consent), and systematic observation checklists. This comprehensive approach allowed researchers to gain insights into both the technical aspects of organic rice farming and the practical decision-making processes of farmers in the region.

Data Analysis

The research methodology employed hierarchical cluster analysis using Ward's method with Euclidean distance to classify organic rice farmers in the Sathing Phra Peninsula based on their production characteristics. This method was chosen for its effectiveness in minimizing within-cluster variance while maximizing between-cluster variance. Prior to analysis, all eight variables (certification patterns, cultivation frequency, farming methods, water source utilization, yield levels, farmland area, seed management practices, and labor utilization) were standardized using z-score transformation to ensure comparable scales regardless of their original measurement units.

The optimal number of clusters was determined through multiple validation methods. First, the agglomeration schedule and dendrogram visualization were examined to identify significant jumps in the fusion coefficients, indicating natural divisions in the data. Second, the elbow method was applied by plotting the within-cluster sum of squares against different numbers of clusters (1–10), revealing a distinct elbow at three clusters. Third, silhouette coefficient analysis was conducted, yielding an average silhouette width of 0.68 for the three-cluster solution, indicating good separation between clusters. These complementary approaches consistently supported a three-cluster solution as the most appropriate representation of farmer groups in the study area.

Following cluster identification, threshold values for key classification variables were established based on statistical analysis of cluster centroids and distribution patterns. The mean values for land holding size across the sample (11.98 rai) and across specific clusters were used as primary classification thresholds. Similarly, yield level thresholds (300–400, 400–500, and >500 kg/rai) were determined based on natural breaks in the data distribution and cluster-specific means. Other categorical variables (certification type, farming approach, water source, etc.) were classified according to their modal values within each cluster, with threshold percentages indicating the predominance of specific practices.

This classification process resulted in the identification of three distinct farmer groups:

(1) Commercial organic farmers (21.28%): Characterized by larger-than-average landholdings (>11.98 rai) and high yields (>500 kg/rai). Statistical analysis of this cluster revealed significantly higher resource utilization and market integration compared to other groups.

(2) Integrated organic farmers (27.66%): Distinguished by moderate landholdings (variable sizes both above and below the sample mean) and medium-range yields (400–500 kg/rai). This group demonstrated a hybrid approach to farming, effectively balancing traditional and modern techniques.

(3) Traditional organic farmers (51.15%): Characterized by smaller landholdings (<10 rai, significantly below the sample mean) and lower yields (300–400 kg/rai). Statistical analysis confirmed this group's stronger adherence to traditional practices and greater reliance on natural resources.

To validate the robustness of this classification, discriminant analysis was performed, resulting in a correct classification rate of 94.70% when farmer group assignments were predicted based on the eight classification variables. Cross-validation using a leave-one-out procedure maintained a correct classification rate of 91.50%, confirming the stability of the identified clusters. One-way analysis of variance (ANOVA) was employed to examine differences between farmer groups and districts. The analysis focused on key variables including cultivation area (measured in rai), rice yield (measured in kg/rai), certification status (group or individual), water source (natural or irrigation), labor utilization patterns, seed variety selection, and production frequency (times/year). Statistical significance was established at $P < 0.05$ for all analyses.

The integration of analytical results was achieved through regular validation of quantitative data against qualitative findings. This approach provided deep insights into the social and cultural contexts and factors influencing farmers' decision-making processes. Additionally, it helped identify challenges and opportunities for developing organic rice production within the specific context of the Sathing Phra Peninsula, considering technical, economic, social, and cultural factors that affect decision-making and farming outcomes across different farmer groups. The comprehensive methodological approach enabled a thorough understanding of not only the technical aspects of organic rice farming but also the complex socio-economic and cultural factors that influence farming practices and outcomes within this unique geographical context.

Ethical Considerations

The study protocol was approved by the Human Research Ethics Committee, Prince of Songkla University (approval no. PSU-HREC-2023-028-1-3). All participants provided informed consent, and traditional agricultural knowledge was documented with appropriate cultural sensitivity and recognition of intellectual property rights. The research process emphasized respectful engagement with local farming communities and protection of participant confidentiality.

RESULTS AND DISCUSSION

Current Situation and Spatial Analysis of Organic Rice Production in Sathing Phra Peninsula

Analysis of rice production in the Sathing Phra Peninsula during the 2022/23 growing season reveals significant spatial variations in organic farming adoption across different districts. As shown in Table 1, the peninsula encompasses 7,072 farming households engaged in rice cultivation, covering a total area of 75,329.48 rai. However, organic rice production represents a remarkably small portion of this total, accounting for only 0.31% (232 rai) of the cultivation area, indicating limited adoption of organic farming practices in the region.

The spatial distribution of rice cultivation across the peninsula's four districts demonstrates notable disparities in organic farming adoption. According to Table 1, Ranot district dominates conventional rice production with 39,990.38 rai, representing 53% of the total cultivation area, yet shows minimal organic adoption at just 40 rai (0.10% of the district area). Singhanakhon district maintains 16,251.71 rai of total cultivation, with organic farming covering 94 rai (0.58%). Interestingly, Krasae Sin district, despite having the smallest total area of 6,920.12 rai, leads in organic adoption with 98 rai, representing 1.42% of its district area. In contrast, Sathing Phra district, with 12,167.27 rai under rice cultivation, has no certified organic rice production.

Analysis of average organic rice cultivation areas among farmers reveals significant variations across districts (Table 2). Ranot district demonstrates the highest average cultivation area per farmer at 20.00 ± 16.97 rai, followed by Krasae Sin district at 7.00 ± 3.19 rai, and Singhanakhon district at 4.48 ±

2.18 rai. However, the substantial standard deviation in Ranot district reflects high variability due to the small sample size (n=2), as evidenced by the wide confidence interval ranging from -132.48 to 172.48 rai.

Statistical analysis using one-way ANOVA, as presented in Table 3, confirms these significant spatial variations in organic rice cultivation patterns ($F = 14.92$, $P < 0.001$). The analysis reveals substantial between-group variance (452.06) compared to within-group variance (515.24), with mean squares of 226.03 between groups and 15.15 within groups. These statistics indicate significant spatial clustering of organic farming practices, suggesting that adoption patterns are influenced by localized factors rather than being randomly distributed across the peninsula.

Post hoc analysis using Duncan's multiple range test revealed that Ranot district had significantly larger average cultivation areas per farmer compared to both Krasae Sin and Singhanakhon districts, while no significant difference was observed between the latter two districts ($P > 0.05$). The concentration of small-scale organic farmers in Singhanakhon district (n=21) with consistent cultivation areas suggests a pattern of smallholder organic farming predominance, whereas Krasae Sin district occupies an intermediate position with moderate cultivation areas and reasonable consistency among its 14 organic farmers.

While the Sathing Phra Peninsula shows strong potential for organic rice farming due to its unique geographical and ecological conditions, several factors contribute to the limited engagement with certified organic rice production, even though it is the only area in Southern Thailand participating in government organic rice promotion projects with commercial production capacity. Economic factors significantly influence farmers' decisions regarding certification. Many farmers in the region traditionally practice organic or near-organic methods but perceive limited economic benefits from formal certification relative to its costs. The peninsula's rice market has developed strong consumer trust based on regional reputation rather than formal certification, with established local markets consistently absorbing all available rice production throughout the year. This reduces the economic incentive to pursue certification, as farmers can already command premium prices through customer relationships and regional branding.

From a social perspective, traditional farming knowledge is deeply embedded in local communities, with many farmers continuing organic practices without certification. Strong consumer confidence in the region's rice quality has created a context in which formal certification adds minimal social capital to producers who are already recognized by their communities. Institutionally, the implementation of government support projects varies across districts, resulting in uneven access to certification resources. While the area participates in government organic rice promotion initiatives, the structure of these programs—initially focusing on a group certification scheme before transitioning to individual certification—may not align with the independent farming practices common in parts of the peninsula. Additionally, infrastructure development patterns, particularly regarding irrigation systems and water access, create spatial disparities in farmers' ability to meet and maintain certification requirements.

This comprehensive spatial analysis reveals that developing organic rice farming in the Sathing Phra Peninsula requires carefully targeted interventions that consider local variations in infrastructure, institutional support, and environmental conditions. The significant district-level disparities in organic adoption rates, as evidenced by Tables 1–2, underscore the importance of developing location-specific strategies rather than applying uniform approaches to promoting organic rice cultivation.

Table 1 Rice production by farmers in Sathing Phra Peninsula, crop year 2022/23

Parameters	Main season rice*		Organic rice**	
	Households	Rai	Farmers	Rai (Percentage)
Sathing Phra Peninsula	7,072	75,329.48	37	232.00 (0.31)
Krasae Sin district	756	6,920.12	14	98.00 (1.42)
Singhanakhon district	1,970	16,251.71	21	94.00 (0.58)
Ranot district	2,490	39,990.38	2	40.00 (0.10)
Sathing Phra district	1,856	12,167.27	0	0.00 (0.00)

Source: Adapted from * the Rice Department (2023) and ** the Department of Agricultural Extension (2023)

Table 2 Average organic rice cultivation areas (rai) of farmers in the Sathing Phra Peninsula

District	N	Mean	SD	SE	95% Confidence interval for mean		Min	Max
					Lower bound	Upper bound		
Singhanakhon	21	4.48	2.18	0.48	3.48	5.47	1	10
Krasae Sin	14	7.00	3.19	0.85	5.16	8.84	4	13
Ranot	2	20.00	16.97	12.00	-132.48	172.48	8	32
Total	37	6.27	5.18	0.85	4.54	8.00	1	32

Table 3 Analysis of variance (ANOVA) between organic rice cultivation areas in Sathing Phra Peninsula

Variable		Sum of squares	df	Mean square	F	P-value
Cultivation area	Between groups	452.06	2	226.03	14.92	0.000*
	Within groups	515.24	34	15.15		
	Total	967.30	36			

Note: * Statistically significant at 0.05 level.

Analysis of Organic Rice Farmer Groups in Sathing Phra Peninsula

Cluster analysis of organic rice farmers in the Sathing Phra Peninsula revealed three distinct groups based on their production characteristics and management approaches, as detailed in Table 4. From all respondents, the analysis identified commercial organic farmers (21.28%), integrated organic farmers (27.66%), and traditional organic farmers (51.15%), each exhibiting unique patterns in cultivation practices, resource management, and certification approaches.

Commercial organic farmers, comprising 21.28% of the sample, are distributed across Krasae Sin (50.00%), Ranot (40.00%), and Singhanakhon (10.00%) districts. These farmers operate on larger landholdings exceeding 11.98 rai and achieve yields above 500 kg/rai. They predominantly utilize group certification schemes (80.00%) while maintaining both organic and conventional farming practices (80.00%). Most commercial organic farmers cultivate rice twice annually (70.00%) using broadcasting methods (90.00%) and have access to both natural and irrigation water sources. Their production systems are characterized by reliance on purchased seeds (56.25%), particularly promoted varieties (70.00%), and they employ a combination of hired and household labor (60.00%).

Integrated organic farmers, representing 27.66% of the sample, are concentrated in Singhanakhon (53.85%) and Krasae Sin (46.15%) districts. This group distinguishes itself by successfully

Table 4 Clustering of organic rice farmers in the area based on similar production characteristics

Characteristics	Group 1: Commercial organic farmers	Group 2: Integrated organic farmers	Group 3: Traditional organic farmers
Proportion	10 farmers (21.28%) Singhanakhon district (10.00%) Krasae Sin district (50.00%) Ranot district (40.00%)	13 farmers (27.66%) Singhanakhon district (53.85%) Krasae Sin district (46.15%)	24 farmers (51.15%) Singhanakhon district (91.67%) Krasae Sin district (8.33%)
Certification status	Currently certified (70.00%) Previously certified (30.00%)	Currently certified (69.23%) Previously certified (30.77%)	Currently certified (62.50%) Previously certified (37.50%)
Type of certification	Group certification scheme (80.00%) Individual scheme (20.00%)	Group certification scheme (100.00%)	Group certification scheme (100.00%)
Rice farming method	Organic-only farming (20.00%) Mixed organic and conventional rice farming (80.00%)	Organic-only farming (53.85%) Mixed organic and conventional rice farming (46.15%)	Organic-only farming (83.33%) Mixed organic and conventional rice farming (16.67%)
Number of rice farming cycles per year	1 time (20.00%) 2 times (70.00%) 3 times (10.00%)	1 time (69.23%) 2 times (30.77%)	1 time (95.83%) 2 times (4.17%)
Rice farming methods	Broadcast sowing/Direct seeding (90.00%) Transplanting (10.00%)	Broadcast sowing/Direct seeding (69.23%) Transplanting (15.38%) Both broadcast sowing and transplanting (15.38%)	Broadcast sowing/Direct seeding (75.00%) Transplanting (16.67%) Both broadcast sowing and transplanting (8.33%)
Water sources	Natural sources (50.00%) Both natural and irrigation (50.00%)	Natural sources (92.31%) Both natural and irrigation (7.69%)	Natural sources only (100.00%)
Sources of rice seeds	Purchase (56.25%) Self-saved (43.75%)	Purchase (53.33%) Self-saved (33.33%) Exchange (13.33%)	Purchase (34.48%) Self-saved (65.52%)
Types of rice varieties	Local varieties (10.00%) Recommended varieties (70.00%) Both local and recommended varieties (20.00%)	Local varieties (7.69%) Recommended varieties (46.15%) Both local and recommended varieties (46.15%)	Local varieties (20.83%) Recommended varieties (16.67%) Both local and recommended varieties (62.50%)
Labor sources for rice production	Hired labor (40.00%) Both hired and household labor (60.00%)	Hired labor (38.46%) Both hired and household labor (61.54%)	Household labor (33.33%) Hired labor (12.50%) Both hired and household labor (54.17%)
Average rice field holdings (rai)	Above average (11.98)	Both below and above average (11.98)	Less than 10 rai
Average yield (kg/rai)	More than 500	400–500	300–400

combining traditional methods with modern technology. All integrated organic farmers participate in group certification schemes, with approximately half focusing exclusively on organic farming (53.85%). They typically cultivate rice once annually (69.23%) using broadcasting methods (69.23%) and rely primarily on natural water sources (92.31%). Their production approach includes purchased seeds (53.33%) of both local and promoted varieties, achieving yields between 400–500 kg/rai through mixed labor utilization (61.54%).

Traditional organic farmers constitute the largest group at 51.15% of the sample, with a strong presence in Singhanakhon district (91.67%). These farmers are characterized by a universal group certification scheme (100.00%) and a strong focus on organic-only farming (83.33%). They predominantly cultivate rice once annually (95.83%) using broadcasting methods (75.00%) and depend entirely on natural water sources (100.00%). Their practices emphasize seed-saving (65.52%) and the use of both local and promoted varieties (62.50%), resulting in yields between 300–400 kg/rai.

The labor utilization patterns demonstrate distinct operational strategies across farmer groups. Commercial organic farmers' reliance on hired and mixed labor systems corresponds to their larger operational scale (>11.98 rai) and intensive cropping patterns (70.00% cultivate twice annually), which exceed household labor capacity. Integrated organic farmers similarly employ mixed labor strategies to balance traditional practices with commercial objectives. In contrast, traditional farmers' greater dependence on household labor aligns with their smaller-scale operations (<10 rai), single cropping cycles (95.83%), and limited financial capacity for hiring external labor, as evidenced by lower yields (300–400 kg/rai). These patterns represent distinct production philosophies: commercial efficiency versus traditional sustainability.

ANOVA results, presented in Table 5, revealed statistically significant differences ($P < 0.05$) across all examined variables among the three farmer groups. Yield variations showed the highest statistical significance ($F = 68.44$, $P = 0.000$), indicating substantial productivity differences between groups. Cultivation frequency also displayed strong variation ($F = 17.27$, $P = 0.000$), followed by significant differences in water source utilization ($F = 11.64$, $P = 0.000$) and farming methods ($F = 7.93$, $P = 0.001$). Farm size showed moderate variation ($F = 6.66$, $P = 0.003$), while certification patterns ($F = 4.33$, $P = 0.019$) and seed management practices, both purchased ($F = 3.77$, $P = 0.031$) and self-saved ($F = 3.42$, $P = 0.042$), exhibited lower but still significant variations.

These findings highlight the heterogeneous nature of organic rice farming in the Sathing Phra Peninsula, where production systems have evolved differently based on resource access, infrastructure availability, and management capabilities. The significant variations across all measured parameters underscore the importance of developing targeted support mechanisms that address the specific needs and constraints of each farmer group. Organic certification in the area is predominantly obtained through a group certification scheme, as most farmers are certified under the Organic Thailand standard. This approach aligns with government policy, which initially emphasizes a group certification scheme before transitioning to individual certification. Group-based promotion strategies offer greater potential for achieving the targeted number of organic rice farmers and the intended cultivation area. The prevalence of group certification schemes across all types suggests strong social organization, although resource access and productivity levels vary considerably among groups. This diversity in farming approaches indicates the need for differentiated development strategies that effectively support the sustainability and growth of organic rice production, while taking into account the unique characteristics and challenges faced by each farmer group.

Integrated Discussion of Organic Rice Production Systems

The analysis of organic rice farming systems in the Sathing Phra Peninsula reveals complex interactions between socio-economic, environmental, and institutional factors that shape agricultural development patterns. This discussion integrates our findings within key theoretical frameworks to provide a comprehensive understanding of the organic rice farming landscape.

Agricultural innovation systems and adoption patterns

The predominance of traditional farmers (51.15%) maintaining conventional production methods contrasts with trends observed in Central Thailand, where farmers increasingly adopt commercial production approaches (Pornpratansombat *et al.*, 2011). This divergence can be explained through Rogers' Innovation Diffusion Theory, particularly regarding the role of infrastructure as a critical adoption barrier. The significant variations in water source utilization among farmer groups, as shown in Table 5 ($F = 11.64$, $P = 0.000$), exemplify how infrastructure access influences innovation adoption patterns. Traditional farmers' complete dependence on natural water sources (100.00%) illustrates this constraint, supporting the assertion of Hussain *et al.* (2006) that irrigation access fundamentally shapes agricultural development trajectories.

Social capital and collective action

The widespread adoption of a group certification scheme across all farmer types (80–100%) demonstrates the significance of social capital in organic farming development. This finding aligns with Social Capital Theory and supports the observations by Rattanasuteerakul and Thapa (2012) about group formation enhancing bargaining power for smallholders. However, the persistent yield disparities between groups (300–500 kg/rai) suggest that social organization alone cannot overcome structural constraints. The variations in market access and price premiums (15–20% between groups) further indicate that social capital benefits are not equally distributed across farmer categories.

Agroecological resilience and resource management

The study reveals distinct patterns in resource management strategies across farmer groups, particularly in seed and water management practices. Traditional farmers' preference for seed-saving (65.52%) contributes to agricultural biodiversity conservation but potentially limits access to improved varieties. This trade-off exemplifies the tension between ecological resilience and productivity enhancement described in Agroecosystem Resilience Theory. The challenge is particularly evident in water management, where 92.31% of integrated organic farmers and 100.00% of traditional farmers rely on natural water sources, increasing their vulnerability to climate variability (Chouichom and Yamao, 2012).

Spatial development and market integration

The spatial distribution of farmer types correlates strongly with infrastructure development and market access patterns. Commercial organic farmers' higher yields (>500 kg/rai) and better market integration demonstrate how spatial factors influence agricultural intensification processes. This relationship supports Spatial Development Theory's emphasis on infrastructure as a catalyst for agricultural transformation. The price premium variations between groups reflect structural market access disparities that cannot be fully addressed through collective action alone.

Table 5 Analysis of variance (ANOVA) among organic rice farmer groups in Sathing Phra Peninsula

Variables		Sum of Squares	df	Mean Square	F	P-value
Certification pattern/type	Between groups	0.32	2	0.16	4.33	0.019
	Within groups	1.60	44	0.04		
	Total	1.92	46			
Number of rice growing cycles	Between groups	5.20	2	2.60	17.27	0.000
	Within groups	6.63	44	0.15		
	Total	11.83	46			
Rice farming method/pattern	Between groups	11.77	2	5.89	7.93	0.001
	Within groups	32.66	44	0.74		
	Total	44.43	46			
Water source	Between groups	1.81	2	0.91	11.64	0.000
	Within groups	3.42	44	0.08		
	Total	5.23	46			
Yield	Between groups	275399.61	2	137699.80	68.44	0.000
	Within groups	88532.31	44	2012.10		
	Total	363931.92	46			
Rice field/paddy field	Between groups	4300.93	2	2150.47	6.66	0.003
	Within groups	14203.41	44	322.81		
	Total	18504.34	46			
Purchased seeds	Between groups	1.68	2	0.84	3.77	0.031
	Within groups	9.81	44	0.22		
	Total	11.49	46			
Self-saved seeds	Between groups	1.42	2	0.71	3.42	0.042
	Within groups	9.14	44	0.21		
	Total	10.55	46			

System integration and adaptation

The analysis of organic rice farming systems in the Sathing Phra Peninsula reveals significant insights into agricultural adaptation and development patterns. The emergence of integrated organic farmers (27.66%) as a successful hybrid group achieving moderate yields (400–500 kg/rai) demonstrates effective adaptation of combined traditional and modern practices. This finding aligns with the recommendations of Bouman *et al.* (2007) for water-efficient rice production systems, while acknowledging existing trade-offs between water efficiency and yield.

Infrastructure, particularly irrigation access, proves crucial in determining production outcomes, supporting Tuong *et al*. (2005) in emphasizing the fundamental importance of water management. Commercial organic farmers with diverse water sources achieve significantly higher yields (>500 kg/rai) compared to traditional organic farmers relying solely on natural sources (300–400 kg/rai). Notably, commercial organic farmers demonstrate that the technology-yield trade-offs observed by Tuong *et al.* (2005) can be mitigated, successfully maintaining high yields while integrating both modern and traditional methods.

Group certification scheme patterns in the peninsula show higher rates (62.50–70.00%) compared to Punyakwao *et al.* (2022) findings in Phayao province (20.56%), likely due to stronger social organization. Both studies emphasize management capabilities' crucial role in successful organic farming adoption, manifesting differently across farmer groups in certification organization and resource management approaches. Technical challenges identified by Hazra *et al.* (2018) present varying impacts across farmer groups. Commercial organic farmers have largely overcome these through better resource access and technology adoption, while integrated organic farmers have developed effective hybrid solutions. Traditional farmers continue facing significant constraints due to limited resource access. The study aligns with the findings of Setboonsarng and Acharya (2015) on organic adoption motivations, particularly regarding institutional support and market access importance. Price premium variations (15.00–20.00%) between groups highlight the critical role of market integration and infrastructure in capturing organic certification benefits.

Policy implications and development pathways

The heterogeneous nature of organic rice farming systems in the peninsula necessitates differentiated policy approaches. Infrastructure development remains critical, particularly for traditional and integrated organic farmers who largely depend on natural water sources. However, the successful adaptation strategies of integrated organic farmers suggest that technological solutions must be combined with traditional knowledge systems. The persistent yield gaps between farmer groups indicate the need for targeted technical support that considers each group's specific constraints and capabilities.

This integrated analysis reveals that organic rice farming development in the Sathing Phra Peninsula requires a systems approach that addresses multiple interconnected challenges. The variation in adoption patterns and outcomes across farmer groups suggests that success depends not only on technical innovations but also on strengthening social institutions and improving market integration. Future development initiatives should focus on 1) enhancing infrastructure access while maintaining ecological resilience, 2) strengthening collective action mechanisms while addressing internal group inequalities, 3) promoting technology adoption while preserving valuable traditional practices, and 4) improving market integration while protecting smallholder interests. These priorities should be pursued through context-specific interventions that recognize the unique characteristics and needs of each farmer group, as evidenced by the significant variations across all measured parameters in the results of this study.

CONCLUSIONS

This study reveals the heterogeneous nature of organic rice farming systems in the Sathing Phra Peninsula through the identification of three distinct farmer typologies with varying adaptation strategies and resource management approaches. The research demonstrates that agricultural development in unique coastal agroecosystems follows differentiated pathways shaped by localized socio-ecological factors, challenging uniform promotional approaches and highlighting the critical importance of context-specific interventions.

The emergence of hybrid farming systems that successfully integrate traditional knowledge with modern technology provides valuable insights for sustainable agricultural development. This hybridization approach offers a viable pathway for enhancing productivity while preserving indigenous agricultural practices, contributing to both food security and cultural preservation in coastal farming communities. The study's findings reveal that infrastructure access, particularly water management systems, serves as a fundamental determinant of farming system evolution and productivity outcomes across different farmer categories.

The research contributes significantly to understanding regional variations in organic agriculture adoption and provides a methodological framework for analyzing agricultural heterogeneity in similar contexts. The cluster analysis approach demonstrates its effectiveness in identifying distinct farmer typologies and can be applied to other agricultural regions facing similar development challenges. These findings have important implications for agricultural policy development, suggesting that successful organic farming promotion requires differentiated support mechanisms that recognize diverse farmer capabilities and resource constraints.

The study's broader significance extends to sustainable agricultural development in coastal regions globally, where unique geographical conditions create specific challenges and opportunities. By demonstrating how social organization can facilitate agricultural transitions while acknowledging uneven benefit distribution, this research provides insights for designing more equitable and effective agricultural development programs. The framework developed here offers policymakers and development practitioners a systematic approach for crafting interventions that simultaneously enhance productivity, strengthen market integration, and preserve valuable traditional practices in diverse agricultural landscapes.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to this research.

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