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Toward Sustainable Agriculture: An Evaluation of Mechanization Practices in Small-Scale Paddy Farming in the Mekong River Delta, Vietnam

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ABSTRACT

This study evaluates mechanization practices in small-scale paddy farming in the Mekong River Delta, following several years of government policies and programs promoting mechanization. Primary data was collected from 1,170 farming households in Hau Giang, Kien Giang, An Giang, and Dong Thap provinces. The mechanization status was assessed based on four key criteria, and mechanization levels were quantified using a cost-based Mechanization Index (MI). The results show high mechanization rates (over 90%) in land preparation, irrigation, fertilization, and harvesting; however, adoption rates were lower in transplanting or sowing (41.2%) and transportation (15.7%). Furthermore, machinery investment has stagnated since 2016, reflecting limited farmer interest in acquiring additional equipment. Advanced mechanization techniques remain experimental as traditional labor-intensive methods continue to dominate farming practices. The calculated MI indicated that 64 percent of households fall into a very low mechanization category. These findings reveal significant limitations of current agricultural policies and underline the need for multidisciplinary and systematic interventions, particularly through the development of self-propelled spreaders, drone sprayers, enhanced linkages between combine harvesters and transportation vehicles, and training on skilled agricultural labor.

Keywords: agricultural mechanization, Mechanization Index, Mekong River Delta, paddy farming
JEL codes: Q01, Q16, Q55

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INTRODUCTION

Agriculture is a fundamental pillar of Vietnam's economy. As the world's second-largest rice exporter, Vietnam reached USD 4,675.81 million in rice exports in 2023, up from USD 3,249.53 million in 2010. The Mekong River Delta (MRD) in southwestern Vietnam is the nation's primary rice-producing region. Covering 2.6 million hectares of agricultural land, it is less than 30 percent of Vietnam's total land area but contributes over 50 percent of the country's rice output. In 2023 alone, the MRD produced 24.2 million tons of rice, accounting for a significant portion of Vietnam's total rice production of 43.5 million tons (GSO 2025).

Despite its importance, paddy farming in the MRD faces several issues, including labor shortages, climate change impacts, and inefficient traditional farming methods (Thuy and Anh 2015; Anh, Hanh, and Shunbo 2019). To address these challenges, agricultural mechanization has been widely recognized as a key solution as it provides benefits such as increased productivity, optimized farming schedules, and improved production efficiency (Bagheri and Bordbar 2014). Agricultural mechanization improves land-use efficiency, enables the expansion of farming areas, meets the demands of large-scale production, saves inputs, creates employment opportunities in rural areas, and mitigates the adverse effects of climate and weather (Nguyen et al. 2020).

Agricultural mechanization can be classified into two main categories: complete and partial mechanization. Complete mechanization refers to the full replacement of human and animal labor with machinery across all farming activities, including land preparation, transplanting, irrigation, fertilization, pest control, harvesting, and postharvest processing. This approach is commonly seen in large-scale commercial farms where productivity and efficiency are prioritized. Partial mechanization, on the other hand, involves a combination of manual labor and mechanical assistance, with certain tasks—such as plowing and harvesting—being mechanized while others, like weeding and irrigation, remain manual. This is more common among smallholder farms, where financial constraints and land size limit the feasibility of full mechanization. Fully mechanized farms have been reported to achieve 10–27 percent higher yields than those employing partial mechanization, while partly mechanized farms outperform non-mechanized ones by 2–26 percent (Balishter and Singh 1991). Additionally, agricultural mechanization indirectly generates employment opportunities for individuals involved in equipment operation, maintenance, and repair (Verma 2006), while simultaneously increasing productivity and production efficiency within the same production area (Bello 2012).

As agricultural mechanization continue to evolve, improving efficiency, sustainability, and productivity in farming systems worldwide, recent studies highlight different aspects of this transformation. Mocanu et al. (2024) explored mechanization in grassland farming, emphasizing minimal-input technologies such as smart sensors for soil and moisture monitoring to enhance productivity and sustainability. Meanwhile, modern agricultural machinery in rice farming in the Philippines was assessed utilizing Modern Portfolio Theory (MPT) to evaluate financial returns, showing that while initial costs are high, benefits include efficiency gains and reduced labor requirements (De Jesus et al. 2024). Another study analyzed mechanization's role in Chinese smallholder farms, using multivalued treatment effect models to show that semi- and full-mechanized systems significantly boost labor and land productivity, though benefits vary by farm size and policy support (Ma and Sun 2024). Nagarjuna et al. (2024) presented a comprehensive review of mechanization's economic, social, and environmental impacts, highlighting precision agriculture's role in sustainable farming and the inequities in technology access. Awachat and Sharma (2024) focused on India's agricultural mechanization, identifying barriers such as limited resources, lack of farmer training, and rising demand for farm machinery. These studies collectively underscore the need for policy-driven support, affordability, and training programs to maximize mechanization's benefits, particularly for small-scale farmers.

To promote mechanization, the Vietnamese government has introduced numerous policies and programs. Resolution No. 26-NQ/TW (PCC 2008) aimed at modernizing agriculture, enhancing research, and facilitating human resource training. Decision No. 2730/QD-BNN-KHCN (MARD 2008) emphasized the role of science and infrastructure in agricultural adaptation to climate change. The Action Plan of the Ministry of Agriculture and Rural Development outlined 16 strategic projects targeting postharvest technologies and mechanization advancements. Additionally, Resolution 48/NQ-CP (Prime Minister of Vietnam 2009) addressed the need for policy frameworks to reduce postharvest losses, while Decision No. 800/QD-TTg (2010) initiated a national program for rural development. Despite these efforts, significant gaps remain in the widespread adoption of mechanization. And notwithstanding the reported rapid growth of mechanization and its unique historical role in Vietnam's economic and social systems, information on agricultural mechanization trends remains limited. Previous studies on Vietnam indicate that mechanization levels vary significantly across regions and farm sizes. Historically, 60–70 percent of land preparation activities have been mechanized, with tractors being the most commonly used equipment. Additionally, 70–80 percent of harvesting activities utilize combine harvesters, making them the predominant machinery in this stage (Takeshima et al. 2018). In contrast, irrigation mechanization is lower, with approximately 50–60 percent of activities relying on pumps and sprinkler systems (Nguyen et al. 2020). However, a comprehensive evaluation of mechanization at the regional scale in the MRD is lacking, making it difficult to assess policy effectiveness and implementation challenges.

Given the MRD's vital role in Vietnam's rice production, it is essential to analyze mechanization trends in the region. This study aims to evaluate the status of mechanization in paddy farming, assess the impact of existing policies, and identify barriers to mechanization adoption. By understanding the extent of mechanization integration and its effectiveness, this research seeks to provide data-driven recommendations for enhancing mechanization in the delta and fostering sustainable agricultural development.

MATERIALS AND METHODS

Data Collection

For the purpose of gathering primary data, the study focused on four provinces within the MRD region, namely, Hau Giang, Kien Giang, An Giang, and Dong Thap. These provinces were selected due to their significant contribution to paddy production, collectively accounting for approximately 55 percent of the total paddy farming area in the delta. The initial project target was to survey 1,400 households equally distributed across five provinces. However, after data cleaning, unqualified observations were removed from the dataset. The final sample consisted of 1,170 paddy farming households, with 270 households from An Giang, 210 from Dong Thap, 250 from Hau Giang, and 200 from Kien Giang. To manage the large sample size efficiently, a convenient sampling method was employed. This approach allowed researchers to effectively gather data within the study's logistical constraints while ensuring coverage of the key rice-producing areas.

The data collection process was conducted through one-on-one interviews with rice farmers in the selected areas. Structured questionnaires were used to gather detailed information on farming practices, mechanization levels, and factors influencing machinery adoption. The structured questionnaire includes general information on households; investment; scale, level, and mechanization growth information; production cost and revenue information; and other information.

In addition to farmer interviews, qualitative discussions were conducted with 10 agricultural extension officers during the data collection period. These officers provided valuable insights into local mechanization trends and challenges. Furthermore, they acted as local guides, facilitating introductions and securing permissions for the research team to conduct interviews with farmers in the selected regions.

Definition of Machinery and Equipment

According to Circular 17/2019/TT-BKHCN issued by the Ministry of Science and Technology (2019), machinery and equipment refer to structural systems composed of interconnected components, assemblies, and parts that enable them to perform specific agricultural functions efficiently. These systems play a crucial role in mechanized farming, enhancing productivity and reducing labor dependency across various agricultural operations.

Paddy farming mechanization in the MRD involves various types of machinery across different farming stages. For example, land preparation utilizes plowing machines, rotary tillers, and multifunctional soil preparation machines, while planting is supported by seeders and rice transplanters. Crop care involves water pumps, fertilizer spreaders, and pesticide sprayers. Harvesting is mechanized with combine harvesters, threshers, and grass balers, while transportation relies on tractors, farm trucks, and trailers. For postharvest processing, drying machines and ventilation fans are commonly used to ensure proper grain storage and preservation.

Concept of Agricultural Mechanization

Agricultural production relies on three interconnected resources: human labor, draft animals, and agricultural machinery. Agricultural mechanization is the process of incorporating machinery, tools, and equipment into agricultural activities to improve efficiency and productivity (FAO 2025). It involves a transition from manual labor to mechanized processes, ranging from simple hand tools to sophisticated automated machinery. Modern mechanization aims to enhance farm labor efficiency, reduce drudgery, and optimize production processes by leveraging technological advancements (Mrema, Kienzle, and Mpagalile 2018). Moreover, mechanization can alleviate the physical burden on farmers, contributing to improved health outcomes (Zhang et al. 2023). Mechanization also plays a crucial role in climate-resilient agriculture by promoting precision farming techniques and resource-efficient practices (Gebresenbet et al. 2023).

The implementation of agricultural mechanization can either partially or fully replace human and animal labor, depending on the level of technology employed. It contributes to optimizing farm operations by reducing physical effort, improving crop yields, and expanding the scale of production. Moreover, mechanization serves as a key driver for large-scale agriculture by enabling land expansion and intensification of production systems (Takeshima, Hatzenbuehler, and Edeh 2020). With advancements in digital agriculture, mechanization now incorporates precision technologies such as GPS-guided tractors, autonomous machinery, and smart irrigation systems, further revolutionizing farming efficiency and sustainability.

METHODOLOGY

Evaluation of the Status of Mechanization

The evaluation of mechanization status requires the use of appropriate indicators since mechanization is a concept that cannot be directly assessed (Zangeneh, Omid, and Akram 2010; 2015). In this study, the approach developed by Nguyen (2018) was adopted to assess the status of mechanization in paddy production. The evaluation is based on four key criteria:

1. ***Scale and level of mechanization.*** Measured by the number of machines or mechanized equipment used per production unit (land area or labor), the proportion of mechanized tasks across different farming stages, and the extent of mechanization.
2. ***Mechanization growth trends.*** Assessed by changes over time in the number of machines purchased, upgraded, or replaced, along with investment trends in agricultural machinery.
3. ***Characteristics of paddy farming households applying mechanization***
4. ***Production results and efficiency.*** Evaluates the impact of mechanization on farm productivity, production costs, and farmers' profits, as well as challenges and limitations faced during mechanization adoption.

Assessment of the Mechanization Level

The mechanization level of small-scale paddy growers in the MRD was assessed using Mechanization Index (MI). In various regions worldwide, assessments of mechanization have been conducted based on the availability and intensity of power or energy (Ramírez et al. 2007; Hormozi, Asoodar, and Abdeshahi 2012; Zangeneh, Omid, and Akram 2015). Previous studies have employed classification systems and indices to quantify the level of mechanization, such as the MI developed by Sharabiani and Ranjbar (2008) and Nowacki (1978). A widely accepted MI is calculated as the ratio of machine energy (including fuel energy and machine energy) to the combined energy of machinery (*EM*), human labor (*EH*), and animal energy (*EA*) (Nowacki 1978) (equation 1). Previous studies have applied this approach to assess the mechanization in agriculture (Abbas et al. 2017; Maheshwari and Tripathi 2019; Sanchavat et al. 2020).

$$MI_E = \frac{E_M}{E_H + E_A + E_M} \tag{1}$$

The *MI* serves as a quantitative measure of the degree of mechanization, with higher values indicating a greater reliance on machinery for agricultural tasks. The calculation of MI, as described in equation (1), forms the basis for evaluating and comparing the intensity of mechanization across different regions in a precise and unbiased manner. However, from an economic standpoint, the index derived from equation (1) does not consider the cost implications associated with energy sources. To address this limitation, Singh (2006) proposed an alternative *MI* that incorporates cost factors into the energy inputs of equation (1):

$$MI_{ij} = \frac{C_{Mij}}{C_{Mij} + C_{Hij} + C_{Aij}} \tag{2}$$

The MI for product i in household j, denoted as MI_{ij}, is determined using equation (2). The formula takes into account various cost factors, including C_{Mij} (the cost of using the machine for product i in household j), C_{Hij} (the labor cost for product i in household j), and C_{Aij} (the cost of using animal power for product i in household j). The selection of this particular MI formula was based on its suitability for the available data and the research objectives. Additionally, this approach indicates the energy and operational capacity of the applied machinery, since higher costs generally correspond with greater horsepower and operational efficiency (Yezekyan et al. 2020). Table 1 presents key machinery and tools used in paddy farming in the MRD, along with their horsepower ratings and operational capacities.

To facilitate interpretation, the calculated MI values were categorized into five groups: non-mechanized ($MI = 0$), very low ($0 < MI \leq 0.25$), low ($0.25 < MI \leq 0.5$), moderate ($0.5 < MI \leq 0.75$), and high ($0.75 < MI \leq 1.00$). This classification allows for a clear understanding of the level of mechanization achieved in each household, with higher index values indicating a greater degree of mechanization.

Table 1. Some machinery types used in paddy farming in the Mekong River Delta

Production Stage	Type of Machine/Tool	Average Power (hp)	Average Price (Million VND)
Land preparation	Multipurpose soil tiller	6.5–8.0	8.0–13.0
	Rotavator	5.5–6.5	8.5–15.5
	Combine tractor	25.0–60.0	30.0–800.0
	Plow	14.0–50.0	32.0–320.0
Sowing	Row seeder	1.5–2.5	0.5–3.0
	Rice transplanter	1.0–19.0	4.0–150.0
Care and maintenance	Sprayer (pesticide application)	0.5–30.0	0.25–10.0
	Water pump	1.0–200.0	1.0–200.0
	Weeder	0.5–30.0	1.5–4.0
	Fertilizer spreader	1.0–30.0	0.7–30.0
Harvesting	Thresher	6.5–20.0	4.0–19.0
	Combine harvester	70.0–84.5	744.0–894.0
	Straw baler	25.0–50.0	45.0–300.0
	Tractor	25.0–60.0	30.0–800.0
Transportation	Agricultural transport vehicle	16.5–24.0	15.0–50.0
Storage and preservation	Dryer	80.0–107.5	76.0–415.0

RESULTS AND DISCUSSION

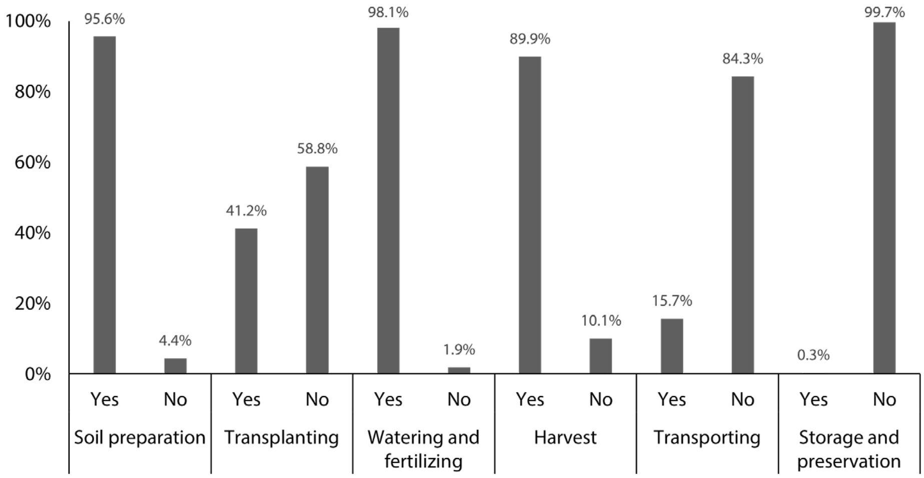
Mechanization Application Status of Paddy Farming Households

Scale and level of mechanization

Small-scale paddy growers in the MRD have shown limited investment in postharvest technologies and storage and preservation procedures. However, they have embraced the use of machines in various other stages of production. As depicted in Figure 1, soil preparation and plant care (water and fertilizing) exhibited the highest application rates at 98.1 percent and 95.6 percent, respectively. Harvesting also demonstrated a significantly high mechanization rate of 89.9 percent, with many farmers opting to hire combine harvesters for efficient crop collection. In contrast, the adoption rates for transplanting or sowing and transportation were relatively lower at 41.2 percent and 15.7 percent, respectively. Overall, it can be concluded that machinery application in paddy farming has become prevalent among small-scale growers. The relatively lower adoption rates of mechanization for the transplanting or sowing stage and transportation among small-scale paddy growers in the MRD can be attributed to several key factors. Firstly, many small-scale farmers in the MRD operate on fragmented plots, making large-scale mechanized transplanting less practical or economically viable. Secondly, mechanized transplanting and transportation equipment require substantial capital, which is often unaffordable for smallholder farmers with limited financial resources. Moreover, this low adoption rate can be attributed to several factors, including the perceived difficulty in using the technology and the limited need for such machinery among small-scale farmers. Farmers in the MRD have traditionally relied on manual labor for transplanting, which remains a common practice due to its cost-effectiveness and suitability for small-scale farming. However, the increasing labor shortages and rising wages have led some farmers to explore mechanized solutions, albeit at a slow pace (Biggs 2012).

The preparation of soil and land is a critical task in paddy farming that has undergone

Figure 1. Machine application rate in paddy farming



significant mechanization through the utilization of soil milling or flip plows. The adoption rate for this activity was found to be 100 percent in all surveyed areas except for Hau Giang, where it stood at 79.2 percent (Table 2). The machines employed for these tasks are typically hired from local services due to the high investment costs associated with tillage machines or tractors, coupled with their infrequent usage by farmers. The emergence of private mechanization service providers has played a pivotal role in agricultural modernization in China since 2004 (Yang et al. 2013). Most farmers rely on machinery to plow, till, or harrow the fields before sowing. Regions that traditionally used draft animals such as buffaloes for plowing have transitioned to raising them for meat. However, there are still a few areas, like Long My district in Hau Giang province and distant areas of Can Tho city, where buffaloes are used in the winter-spring (W-S) season due to the excessively swampy soil that renders tractors ineffective. The commonly utilized tractors typically have a horsepower (hp) ranging from 25 to 60 and hired soil preparation costs of approximately VND[1] 1.30–1.50 million/ha (USD 52.78–60.90/ha). Given that tractor prices range from VND 30 to 800 million (depending on the operating capacity), the cost of purchasing a tractor is approximately 20 to 533 times higher than the cost of hiring local mechanization services for plowing per hectare. Due to this significant cost difference, farmers prefer to rent machinery rather than invest in their own tractors. The widespread adoption of tractors as a labor and draft animal substitute is a prevailing trend in various Asian countries (Mano, Takahashi, and Otsuka 2020).

In the transplanting or sowing stage, manual labor or shoulder spreaders are commonly used for seed sowing. Manual sowing has a productivity rate of 1.5 ha/working day, with labor cost ranging from VND 200,000 to 400,000/ha (USD 8.12–16.24/ha). Seed required varies from 120 to 300 kg/ha, with higher elevation lands tending to sow more densely than lowlands. Despite the introduction of rice transplanting as an alternative to manual sowing, its adoption remains limited. Many farmers resist change due to their adherence to traditional sowing practices. Furthermore, rice transplanting entails additional effort and costs for seedling preparation compared to conventional wide-bed sowing. However, there has been a gradual increase in the adoption of seed-sowing machines and rice transplanters. The use of rice transplanters helps reduce seed requirements, as well as the use of fertilizers, pesticides, and manual labor, thereby increasing farmers' profitability.

1 Vietnamese Dong

Table 2. Machine application rates in the Mekong River Delta (%)

Production Stage		An Giang	Dong Thap	Hau Giang	Kien Giang	Soc Trang
Soil preparation	Yes	100.0	100.0	79.2	100.0	100.0
	No	0	0	20.8	0	0
Transplanting/sowing	Yes	50.7	38.1	26.0	100.0	0
	No	49.3	61.9	74.0	0	100.0
Watering and fertilizing	Yes	96.7	100.0	96.8	100.0	97.9
	No	3.3	0	3.2	0	2.1
Harvest	Yes	100.0	98.1	68.4	100.0	85.4
	No	0	1.9	31.6	0	14.6
Transporting	Yes	3.0	0	4.4	6.5	63.3
	No	97.0	100.0	95.6	93.5	36.7
Storage and preservation	Yes	0	1.9	0	0	0
	No	100.0	98.1	100.0	100.0	100.0

Regarding plant care activities, such as watering, fertilizing, and pesticide application, machines are extensively employed in almost all rice fields in the MRD for irrigation purposes. The primary engines used for irrigation are fuel-powered water pumps that operate on gasoline or diesel. Large-scale production often relies on high-capacity pumping stations to meet the water demand during periods of high flow. In the absence of rainfall, one hectare of land typically requires 7–9 pumping cycles per growing season, with each cycle lasting 3–4 hours. The service price for pumping water is approximately VND 30,000/hour (USD 1.22/hour), equivalent to VND 650,000 to one million/ha (USD 26.39–40.60/ha).

Paddy growers typically apply fertilizers three times per season, either using shoulder spreaders or manual methods. Manual fertilizer application is associated with low productivity and uneven distribution of nutrients. The cost of hiring workers for this activity is approximately VND 1,000/kg (around VND 50,000/bag ~ USD 2.03/bag). The standard quantity applied per season is 500 kg/ha, equivalent to VND 500,000/ha (USD 20.30/ha). In recent years, various agricultural promotion projects and programs have introduced self-propelled fertilizer spreaders in the MRD. These spreaders offer high productivity, reaching up to 6.0 ha/hour, which is crucial for large-scale fields. Preliminary experiments have shown that the adoption cost of self-propelled spreaders is VND 130,000/ha (USD 5.28/ha), which is 75 percent lower compared to manual fertilization. However, their practical use is still limited, necessitating further research to highlight their advantages.

Pesticide spraying, particularly manual spraying, poses significant risks to human health. Currently, farmers commonly use backpack sprayers for small-scale fields, which cost between VND 150,000 and 200,000/ha (USD 6.09–8.12 /ha). In certain areas, combined spraying systems incorporating air compressors, large containers, and spray hoses have been implemented. The cost of renting such systems is approximately VND 140,000/ha (equivalent to VND 70,000/tank ~ USD 2.84/tank), with each hectare typically requiring two pesticide tanks, approximately 200 liters in total. Moreover, there have been experiments with self-propelled pesticide spreaders in certain locations, capable of spraying over 10 ha of rice fields per day. Drone sprayers have also been utilized but mainly on large-scale farms.

In harvesting, a significant portion of the rice yield is collected using combine harvesters, approximately 95 percent of which are Kubota. Once the grains are harvested, they are transported to collection sites using specialized vehicles.

Subsequently, they are transferred to factories for postharvest processes either by boats or trucks. The introduction of mechanization has led to a reduction in harvesting fees, ranging from VND 1.10–1.62 million/ha (USD 44.66–64.96/ha) and even lower for large-scale fields. Additionally, the transportation cost for delivering the crops to collection sites is approximately VND 400,000 to 500,000/ha (USD 16.24–20.30/ha). The harvesting cost typically constitutes 4 percent to 8 percent of the total production cost, which varies depending on the season and the quality of the harvested grains.

Agricultural mechanization growth

From 2016 to 2019, there was a lack of recorded investment in new machinery among rice farming households. This can be attributed to the fact that surveyed farmers have been involved in paddy production for an average of 21 years, indicating that machinery expenditures were made earlier than 2016. Additionally, the existing machines and devices owned by farmers are relatively simple in structure and easy to repair, such as water pumps or shoulder spreaders, leading to a low demand for further machinery investment. A similar trend of sluggish growth in farm mechanization (less than 5%) was observed in India from 1994 to 2014 (Mehta, Chandel, and Senthilkumar 2014).

Although the number of machines and production scale of households have remained unchanged between 2016 and 2019, there have been minor developments in certain production stages (Table 3). For instance, the mechanized transplanting or sowing area has increased from 37 to 39 percent during W-S season (2016–19), while the mechanized weeding and pesticide spraying area has increased from 64 to 68 percent in the same season and from 56 to 59 percent in autumn-winter (A-W) season. These marginal increases indicate the need for the government to explore alternative approaches to encourage and incentivize farmers to invest in new machinery, thereby expanding the mechanized area and enhancing the adoption of advanced technologies.

Regarding the intention to acquire additional supporting machines and technologies, 69.7 percent of the households surveyed expressed satisfaction with their current devices, stating that their existing machinery already fulfills their needs, and therefore, there is no requirement for further investment. These opinions were collected from the study areas in An Giang, Dong Thap, Hau Giang, and Kien Giang provinces (Table 4). In contrast, 82.9 percent of households particularly in Soc Trang province expressed a desire to make further machinery investments. Their motivations included increasing output yields, reducing labor costs, minimizing manual labor, ensuring output quality, and maintaining farming schedules. These opinions align with the perception of farm mechanization among farmers in Bangladesh (Vortia et al. 2021).

The activities that were identified as requiring more investment in mechanization include soil preparation, transplanting, plant care, and harvest. Among these, the highest intention for increased investment was observed in Soc Trang province, where 93 percent of households expressed a desire to allocate more resources to soil preparation, and 86.7 percent expressed the same for the harvest stage.

The stagnant growth of mechanization and the low inclination for investment since 2016 underscore the insufficiency of existing policies and programs aimed at promoting the adoption of advanced agricultural technologies in the MRD. Despite the implementation of several pilot models to encourage agricultural development (such as the System of Rice Intensification or SRI; Three Reductions, Three Gains or 3R3G; One Must Do, Five Reductions or 1M5R; and One Must Do, Six Reductions or 1M6R), most rice farmers still perceive traditional cultivation methods and basic machinery as adequate to meet their current demands.

Table 3. Proportion of paddy farming area with mechanization adoption over time (%)

Stage of Production	Winter-Spring (W-S) Crop				Summer-Autumn (S-A) Crop				Autumn-Winter (A-W) Crop			
	2016	2017	2018	2019	2016	2017	2018	2019	2016	2017	2018	2019
Land preparation	92	92	92	92	92	92	92	91	82	82	82	82
Sowing and transplanting	37	38	38	39	37	37	38	38	36	36	36	36
Direct seeding	37	37	38	38	37	37	37	38	36	36	36	36
Transplanting	0	0	0	0	0	0	0	0	0	0	0	0
Weeding and spraying	64	64	68	68	64	64	68	67	56	56	61	59
Irrigation	47	47	47	47	51	51	52	52	44	44	45	44
Fertilization	44	44	45	45	44	44	45	45	43	43	43	44
Harvesting	60	60	60	61	60	60	60	61	50	50	50	51
Multi-stage harvesting (rice cutting)	16	16	15	16	15	15	15	15	14	14	14	14
Multi-stage harvesting (threshing)	1	1	1	1	1	1	1	1	1	1	1	1
Single-stage harvesting	44	44	45	45	45	45	45	46	37	37	37	38
Transportation, storage, preservation, and processing	0	0	0	0	0	0	0	0	0	0	0	0
Drying	1	1	1	1	0	0	0	0	0	0	0	0

Table 4. Intention of paddy farmers to invest in machinery

	%	Total sample	An Giang	Dong Thap	Hau Giang	Kien Giang	Soc Trang
Further investment in machinery	Yes	30.3	18.5	3.8	17.2	27.0	82.9
	No	69.7	81.5	96.2	82.8	73.0	17.1
Soil preparation	Yes	27.0	9.3	0.0	5.2	27.0	93.3
	No	73.0	90.7	100.0	94.8	73.0	6.7
Sowing/ transplanting	Yes	12.2	3.0	0.0	12.0	7.0	37.9
	No	87.8	97.0	100.0	88.0	93.0	62.1
Plant care	Yes	18.8	6.3	0.0	12.8	27.0	48.8
	No	81.2	93.7	100.0	87.2	73.0	51.3
Harvest	Yes	21.9	3.3	1.9	8.8	6.5	86.7
	No	78.1	96.7	98.1	91.2	93.5	13.3
Storage and preservation	Yes	2.8	0.0	0.0	1.2	0.0	12.5
	No	97.2	100.0	100.0	98.8	100.0	87.5
Processing	Yes	1.0	0.0	0.0	0.8	0.0	4.2
	No	99.0	100.0	100.0	99.2	100.0	95.8

Characteristics of households applying agricultural mechanization

The average size of paddy fields in the MRD is 5.4 ha, with the smallest field measuring 0.1 ha and the largest spanning 70 ha. There are variations in production scales among provinces, with An Giang averaging 2.9 ha, Dong Thap 1.1 ha, Hau Giang 0.04 ha, and Soc Trang 2.05 ha. Notably, there are households cultivating areas as large as 60–70 hectares. Although farmers allocate a small portion of their land for other crops, livestock, or aquaculture, paddy farming remains the primary focus. The prevalence of small-scale farms posed challenges for mechanization, as it contradicted the principle of economies of scale, particularly in terms of individual ownership of expensive machinery (Mehta et al. 2014).

In recent years, there has been a noticeable trend of labor migration from rural to urban areas in search of employment opportunities in industrial zones (Anh, Hanh, and Shunbo 2019). The agriculture sector consequently experienced a decline in the available workforce, necessitating the promotion of industrialization and modernization to attract more laborers. On average, a household in the MRD has five members, with two directly involved in paddy farming. Farmers in the region have an average of 27 years of experience, indicating their long-standing engagement in this livelihood. However, formal education levels are generally limited to lower secondary education, as individuals typically discontinue schooling after six years (Table 5). As a result of limited education, many farmers rely on knowledge passed down from their predecessors and friends to operate farm machinery, leading to suboptimal utilization of the equipment and productivity losses. Rural areas often face a scarcity of skilled mechanics who could repair and maintain farming tools, machines, and equipment. Therefore, there is a significant demand for skilled workers to operate high-tech agricultural systems, particularly in large companies and enterprises.

To effectively utilize the various types of machines and accommodate the design differences in paddy farming, it is crucial for operators to possess adequate knowledge to optimize their usage and mitigate the risk of injuries (Robert, Elisabeth, and Josef 2015). However, according to Table 6, only a mere 23.7 percent of the households surveyed received training on agricultural modernization and technologies. The attendance rate varies among provinces, with Dong Thap having the highest rate at 39 percent, while An Giang had the lowest rate at only 3.3 percent. Notable pilot models have been implemented, such as the Ideal Rice Farming Model in Dong Thap; the Shrimp-Rice Farming Model in Kien Giang (62,500 ha), Ca Mau (46,000 ha), Bac Lieu (40,000 ha), and Soc Trang (7,500 ha); as well as the Smart Rice Farming Model and the Large-Scale Fields in Kien Giang. However, only a few farmers have had the opportunity to participate in these deployment programs. Therefore, the authorities must prioritize providing additional training and creating opportunities for more individuals to engage actively in the promotion of agricultural modernization.

Table 5. Characteristics of farming households

Characteristics	Unit	Mean
Educational level	Years	7
Household size	People	5
Male	People	2
Female	People	2
Employed members	People	3
Paddy farming members	People	2
Know-how to use machines	People	1
Officially trained or educated about machinery	People	1
Farming experiment	Years	27

Table 6. Training on machinery and technologies

		Share (%)	Mean
Attended training	Yes	23.7	
	No	76.3	
Number of training/year			0.43

Production results and efficiency of paddy farming households

The benefits of mechanization in rice farming have been well established in previous studies. For instance, the utilization of rice transplanters has led to a reduction in seed amounts to 40–50 kg/ha, shortened the growing season to 15–20 days, and facilitated the use of other harvesting machinery. Additionally, the adoption of combined harvesters could result in a 60 percent reduction in harvest costs. If mechanization is implemented in all stages of production, the total cost can be reduced by VND 2.32–2.51 million/ha (USD 93.38–101.50/ha). Scaling this cost reduction across the 40.7 million ha of rice fields in the MRD would amount to approximately VND 10,000 billion (USD 406,009) (Tuan 2013).

In this study, paddy growers in the provinces of the MRD, except in Kien Giang, engage in three planting seasons per year. Among these provinces, An Giang achieved the highest yield, surpassing 22 t/household per season. In general, the revenue and profit generated from rice production in the region have yielded remarkable outcomes. As indicated in Table 7, farmers in four out of the five surveyed provinces generated revenue and profit levels significantly higher than their input costs. Notably in An Giang and Hau Giang, every VND invested resulted in triple the revenue and double the profit. However, it cannot be concluded that these results are solely attributable to machinery application, as there have been numerous advancements in cultivation techniques, crop varieties, irrigation practices, land-use changes, and management approaches that have contributed to the development of paddy production in the MRD (Nguyen 2007; Chu, Suhardiman, and Le 2014; Kontgis, Schneider, and Ozdogan 2015).

The Mechanization Index of Paddy Farming Households

Figure 2 illustrates the computed MI values for paddy farming households in the MRD. The average MI value for the region is 0.2, with a maximum value of 0.9, and a minimum value of 0. These results indicate the very low level of mechanization of the majority of households, accounting for 64 percent of the sample. Additionally, 26 percent has low MI, while 3 percent and 2 percent have moderate and high MIs, respectively. It is noteworthy that approximately 5 percent of the surveyed households has an MI of zero, indicating a complete absence of mechanization in their production practices. Comparing these findings to a similar assessment conducted in India (Singh 2006), the average MI in Vietnam (0.2) was higher than that in India (0.02). However, it is important to consider the temporal

Table 7. Paddy production results in the Mekong River Delta

	An Giang	Dong Thap	Hau Giang	Kien Giang	Soc Trang
	Mean	Mean	Mean	Mean	Mean
W-S yield (tons)	27.428^{a}	5.695^{b}	9.364^{b,c}	12.236^{c}	12.960^{c,d}
S-A yield (tons)	22.636^{a}	4.611^{b}	7.380^{b,c}	9.123^{c}	12.960^{d}
A-W yield (tons)	24.379^{a}	5.064^{b}	5.846^{b}	.000^{c}	12.960^{d}
Total cost per year (million VND)	88.42^{a}	43.05^{b,c}	32.91^{b}	48.63^{c}	76.83^{d}
Revenue per year (million VND)	227.36^{a}	90.36^{b,c}	88.71^{b,c}	117.41^{b}	65.47^{c}
Profit per year (million VND)	138.94^{a}	47.32^{b}	55.80^{b}	68.77^{b}	–11.36^{c}
Revenue/cost	3.00^{a,b}	2.43^{a}	3.07^{b}	2.75^{a,b}	0.85^{c}
Profit/cost	2.00^{a,b}	1.43^{a}	2.07^{b}	1.75^{a,b}	–0.15^{c}
Profit/revenue	0.18^{a}	0.21^{a}	0.54^{b}	0.01^{a}	–0.49^{c}

Note: Values in the same row followed by different superscripts (a, b, c, d) are significantly different ($p < 0.05$).

Table 8. Comparison of mechanization indices

	Percent (%)	An Giang	Dong Thap	Hau Giang	Kien Giang	Soc Trang
W-S season	Non-mechanized	0.0	3.8	12.4	13.0	0.0
	Very low	49.3	73.3	70.8	46.5	54.2
	Low	44.1	11.4	15.6	19.5	45.8
	Moderate	3.3	5.7	0.4	21.0	0.0
	High	3.3	5.7	0.8	0.0	0.0
S-A season	Non-mechanized	0.0	5.7	11.6	13.0	0.0
	Very low	49.3	64.3	73.2	46.5	54.2
	Low	40.7	14.8	14.0	19.5	45.8
	Moderate	6.7	11.4	0.4	14.0	0.0
	High	3.3	3.8	0.8	7.0	0.0
A-W season	Non-mechanized	6.3	7.6	60.0	100.0	0.0
	Very low	49.3	64.3	32.0	0.0	54.2
	Low	34.4	12.9	6.8	0.0	45.8
	Moderate	3.3	11.4	0.4	0.0	0.0
	High	6.7	3.8	0.8	0.0	0.0

gap between the two studies. A study conducted in Indonesia also revealed a very limited utilization of mechanical power in small-scale rice farming, which was primarily limited to land preparation, threshing, and milling (Paman, Inaba, and Uchida 2014).

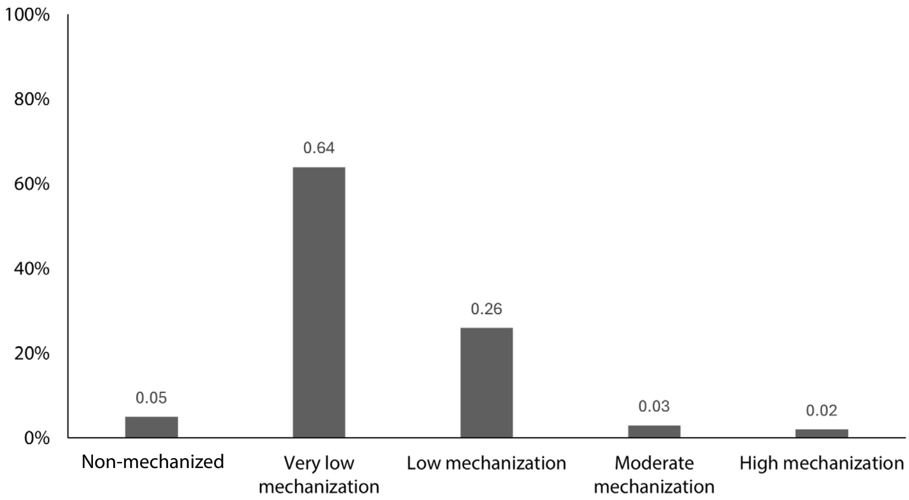
Based on the data presented in Table 8, the MI values for the W-S and summer-autumn (S-A) seasons are relatively similar, indicating comparable levels of mechanization. Both seasons exhibit an average MI of approximately 0.21 and show similar distributions across the very low (approximately 65%) and low (around 26%) mechanization categories. Among the surveyed locations, Kien Giang had the highest average MI of 0.27, followed by An Giang with 0.25, Soc Trang with 0.24, Dong Thap with 0.19, and Hau Giang with 0.12. These rankings are consistent with the results observed during the W-S season. Similarly, for the S-A season, the average MI is 0.22, with 57.6 percent of the sample falling into the very low mechanization category and 27.8 percent in the low mechanization category. The rankings among the study areas closely mirror those of the W-S season.

In contrast to the W-S and S-A rice crops, the A-W season exhibits a significantly lower level of mechanization. The average MI for the A-W season is merely 0.15, primarily due to variations in production areas and machine usage intensity across different growing seasons. Notably, a substantial proportion of households, approximately 32.7 percent, has non-mechanized rice production during the A-W season. The very low mechanization category remained dominant, encompassing 41 percent of the sample. Among the study areas, An Giang has the highest estimated MI of 0.24, while Hau Giang has the lowest at 0.06.

CONCLUSIONS AND RECOMMENDATIONS

Assessing the status of mechanization, agricultural productivity, and socioeconomic characteristics of a region play a crucial role in ensuring the sustainability of agriculture. In the MRD, machinery adoption in paddy farming remains limited in intensity, prevalence, and growth. Most mechanized equipment is designed for small-scale and fragmented rice fields. Additionally, since many farmers sell harvested crops quickly to middlemen, investment in modern storage and preservation technologies remains minimal. However, some stages of rice production, such as soil preparation and crop care, exhibit higher mechanization rates.

Figure 2. Calculated mechanization index of paddy farming in the Mekong River Delta



Between 2016 and 2019, there was little to no growth in machinery investment, indicating that rice farmers had limited intent to acquire additional equipment. This trend suggests that government initiatives promoting agricultural modernization have not effectively driven increased mechanization over the past five years. Although various new farming techniques have been introduced and tested, traditional methods remain dominant, reducing the demand for further mechanization.

The calculated MI reveals an average value of just 0.2 for the MRD, with approximately 64 percent of households classified under very low mechanization levels. These findings highlight the significant gap in mechanization adoption and emphasize the need for alternative strategies to achieve national agricultural modernization targets.

In light of the aforementioned considerations, this study proposes several solutions for the advancement of paddy production and mechanization. Given the future trend toward concentrated and large-scale production, shoulder spreaders will become inadequate for fertilizer and pesticide application due to their limited productivity. Thus, it is crucial to invest in the research and development of self-propelled spreaders and drone sprayers, which offer effective solutions for reducing manual labor and minimizing the adverse effects of pesticides on human health. These devices have been experimentally validated and demonstrate high feasibility, with the next step being the reduction of their cost and practical deployment.

While combine harvesters have been widely adopted and proven effective, human involvement is still required in the packing and shipping processes of harvested yields. It is thus suggested to establish a linkage between combine harvesters and transport vehicles. This entails directly pouring the rice harvested by the machines into vehicles that move in parallel across the fields. This approach eliminates the need for manual packing and transportation of crops from the fields to collection sites, thereby reducing delivery time to processing factories. Similar practices have been successfully implemented on large-scale fields globally, making it more convenient to transfer rice to drying systems at the factories.

Furthermore, the education and training of skilled laborers in the agriculture sector are essential to meet future development trends. Education programs should prioritize practical and specific aspects of agricultural mechanical engineering. Offering scholarships, reducing tuition fees, and implementing employee referral programs are among the strategies that can attract more young individuals to study agricultural mechanical engineering. Additionally, establishing strong linkages between training institutions and enterprises will provide students with more opportunities to work with the latest and most advanced machines and devices.

This study is limited to data from 2016 to 2019, and due to the rapid advancement of technology, future studies should cover extended periods to track long-term trends and reflect the latest developments in agricultural mechanization.

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