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ECONOMIC IMPACTS OF AGRICULTURAL TECHNOLOGY USE ON RICE PRODUCTION VALUE IN MECHANIZED PADDY SYSTEMS

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ABSTRACT

Agricultural technology adoption is widely promoted to improve rice productivity; however, its economic impacts within mechanized farming systems remain insufficiently understood from a system-level perspective. This study addresses this gap by examining how technology use influences rice production value within integrated paddy systems. A cross-sectional survey of rice farmers operating in mechanized lowland systems was conducted. Data were analyzed using a multiple linear regression framework to assess the economic effects of agricultural technology use alongside conventional production inputs, with production value employed as the primary performance indicator. The results indicate that agricultural technology use positively influences rice production value, although impacts vary across technology types. Technologies addressing critical production constraints exhibit stronger economic effects than labor-substituting tools. The overall model demonstrates high explanatory power, confirming the relevance of technology adoption within the broader farming system. The findings suggest that technology contributes to economic performance through efficiency-enhancing pathways and improved resource allocation rather than uniform input intensification, highlighting the importance of system coherence. This study provides empirical evidence that context-specific and integrated technology adoption strengthens economic efficiency and supports sustainable mechanized rice farming systems.

Keywords:
adopsi teknologi, efisiensi ekonomi, intensifikasi berkelanjutan, nilai produksi, pertanian mekanis, pertanian skala kecil.

ABSTRACT

Adopsi teknologi pertanian dipromosikan secara luas untuk meningkatkan produktivitas padi; namun, dampak ekonominya dalam sistem pertanian mekanisasi masih kurang dipahami dari perspektif tingkat sistem. Studi ini mengatasi kesenjangan tersebut dengan meneliti bagaimana penggunaan teknologi memengaruhi nilai produksi padi dalam sistem sawah terintegrasi. Survei lintas sektoral terhadap petani padi yang beroperasi di sistem sawah mekanisasi dataran rendah dilakukan. Data dianalisis menggunakan kerangka regresi linier berganda untuk menilai efek ekonomi dari penggunaan teknologi pertanian bersamaan dengan input produksi konvensional, dengan nilai produksi digunakan sebagai indikator kinerja utama. Hasil menunjukkan bahwa penggunaan teknologi pertanian secara positif memengaruhi nilai produksi padi, meskipun dampaknya bervariasi di berbagai jenis teknologi. Teknologi yang mengatasi kendala produksi kritis menunjukkan efek ekonomi yang lebih kuat daripada alat pengganti tenaga kerja. Model keseluruhan menunjukkan daya penjelas yang tinggi, yang menegaskan relevansi adopsi teknologi dalam sistem pertanian yang lebih luas. Temuan menunjukkan bahwa teknologi berkontribusi pada kinerja ekonomi melalui jalur peningkatan efisiensi dan alokasi sumber daya yang lebih baik daripada intensifikasi input yang seragam, yang menyoroti pentingnya koherensi sistem. Studi ini memberikan bukti empiris bahwa adopsi teknologi *yang spesifik konteks dan terintegrasi memperkuat efisiensi ekonomi dan mendukung sistem pertanian padi mekanisasi yang berkelanjutan.*

INTRODUCTION

The current transformation of the global agricultural system is aimed at increasing productivity and economic efficiency without sacrificing the sustainability of natural resources (Suherman et al., 2023). In the context of food agriculture, particularly rice, pressure on production systems is increasing due to population growth, limited land, climate change, and rising input costs (Peter & Peng, 2014). Therefore, the adoption of agricultural technology is seen as a key instrument for strengthening the economic performance and competitiveness of modern agricultural systems (Ahmed & Ahmed, 2023; Rehman et al., 2016).

The use of agricultural technologies, such as mechanized tillage, the use of superior seeds, balanced fertilization, and technology-based pest control, has been proven to increase the productivity and efficiency of farming in various developing countries (Gautam et al., 2023; Nurhapsa & Suherman, 2023; Roy et al., 2023). However, most international studies still focus solely on the impact of technology on production yields or technical efficiency, while its impact on production value, as an indicator of the economic performance of agricultural systems, has received relatively limited comprehensive discussion (Balafoutis et al., 2017; Jin et al., 2010). Yet, production value reflects the integration of physical productivity, output prices, and farmer managerial decisions within a farming system (Le Gal et al., 2010; Shodiq, 2022).

In increasingly mechanized rice farming systems, technology adoption does not occur in isolation but interacts with farmers' socioeconomic factors, cost structures, and agroecosystem characteristics (García et al., 2012; Nirwan et al., 2019). An integrated farming systems approach emphasizes that technology must be understood as part of a production system interconnected by technical, economic, and institutional components (Hadi et al., 2021; Moraine et al., 2014; Suherman et al., 2024). Therefore, the economic impact of technology use needs to be analyzed within the framework of the entire farming system, not as isolated, partial interventions (Bowman & Zilberman, 2013).

At the smallholder level, particularly in lowland rice paddy systems that have undergone intensification and mechanization, a gap remains between the potential of technology and the realization of economic benefits (Awio et al., 2022; Noltze et al., 2012; Takeshima & Mano, 2023). Several studies have shown that technology adoption does not always lead to increased income or production value if it is not accompanied by adequate business scale, access to inputs, and farmer managerial capacity (Muzari et al., 2012; Suherman et al., 2024). This situation highlights a significant research gap regarding how the use of agricultural technology affects the value of rice production in the context of mechanized farming systems (Liu & Li, 2023; Min et al., 2021).

Based on this background, the novelty of this research lies in its approach to analyzing the economic impact of agricultural technology on rice production within an integrated and mechanized rice farming system. This research not only assesses the contribution of individual technologies but also positions them as part of a production system influenced by cost, labor, and farm characteristics.

Thus, the objective of this study is to analyze the impact of agricultural technology use on the production value of rice farming in mechanized rice paddy systems and to identify the role of technology in sustainably improving the economic performance of agricultural systems. The research findings are expected to provide empirical contributions to the development of technology-based agricultural policies that are not only productive but also efficient and sustainable.

RESEARCH METHODS

Study Area and Farming System Characteristics

This study was conducted in a mechanized lowland rice production area characterized by intensive paddy farming systems and relatively high adoption of agricultural technologies. The region represents a typical mechanized paddy system where farmers combine land preparation machinery, improved seed varieties, chemical inputs, and labor-saving technologies within smallholder production structures. Such systems provide an appropriate context for assessing the economic impacts of agricultural technology use within an integrated farming system framework.

Data Collection and Sampling Technique

The research employed a cross-sectional survey design. Primary data were collected through structured interviews with rice farmers using a pre-tested questionnaire. The sampling method followed a purposive approach, targeting farmers actively engaged in rice cultivation and utilizing at least one form of agricultural technology during the production season. This approach ensured the relevance of observations to the research objective of analyzing technology adoption and its economic implications. Data collected included production value, input costs, labor use, and technology-related variables, as well as socio-economic characteristics of farmers. Production value was measured as the monetary value of harvested rice, reflecting both yield performance and market price conditions.

Analytical Framework: Technology Adoption and Economic Impact

To evaluate the economic impacts of agricultural technology use, this study adopted an econometric approach grounded in production economics. The analytical framework conceptualizes technology adoption as an integral component of the rice farming system that influences production value through its interaction with conventional production inputs.

A multiple linear regression model was employed to estimate the relationship between agricultural technology use and rice production value. The general model specification is expressed as:

$$Y=\alpha+\beta 1X1+\beta 2X2+\beta 3X3+\beta 4X4+\beta 5X5+\varepsilon \quad (1)$$

Where Y represents rice production value, X_1 denotes land area, X_2 labor input, X_3 seed cost, X_4 fertilizer cost, and X_5 agricultural technology use. The error term ε captures unobserved factors affecting production value.

The technology variable reflects farmers' utilization of mechanized tools and modern production practices, consistent with the mechanized paddy system under study.

Model Estimation and Diagnostic Testing

The regression model was estimated using ordinary least squares (OLS). Prior to interpretation, standard diagnostic tests were conducted to ensure the validity of the estimation results, including tests for multicollinearity, heteroscedasticity, and overall model significance. These tests ensured that the estimated coefficients reliably captured the economic effects of technology adoption within the farming system.

Interpretation within an Integrated and Sustainable Agriculture Context

The estimated coefficients were interpreted within a systems-based perspective, emphasizing how the use of agricultural technology contributes to production value through improved efficiency, labor productivity, and resource allocation. Rather than treating technology as an isolated input, this study positioned technology adoption as part of an integrated production system that shapes economic performance in mechanized paddy farming.

Ethical Considerations

This study adhered to fundamental ethical principles in social and agricultural research. Participation of respondents was entirely voluntary, and informed consent was obtained before data collection. Respondents were provided with clear information regarding the purpose of the study, the type of data collected, and the intended use of the results for academic and policy-related purposes.

All data collected from farmers were treated confidentially and anonymized to protect respondents' identities. Personal identifiers were excluded from the dataset, and information was analyzed and reported only in aggregate. The research did not involve any physical, psychological, or social risk to participants and complied with ethical standards for research involving human subjects.

RESULTS

Characteristics of Rice Farming Systems

Descriptive statistics of the rice farming systems are presented in Table 1. The average farm size was relatively small, reflecting the dominance of smallholder farming structures within mechanized lowland paddy systems. Labor use varied considerably among farmers, indicating differences in management intensity and reliance on hired labor. Input costs for seeds, fertilizers, and agricultural technologies showed moderate variation, suggesting relatively uniform production practices across the study area.

Table 1. Characteristics of rice farming systems in the study area

Variable	Unit	Mean	Minimum	Maximum
Farm size	ha	1.18	0.25	2.50
Labor use	HOK	75.07	39.00	148.00
Seed cost	IDR/season	337,797	308,000	398,871
Fertilizer cost	IDR/season	85,388	75,066	100,202
Technology cost	IDR/season	384,246	337,797	450,900
Production value	IDR/season	11,997,000	9,500,000	16,014,000

Note: Values are calculated from 95 rice farmers operating within mechanized lowland paddy systems.

The mean production value indicates that rice farming remains economically significant within the local agricultural system. These characteristics illustrate that rice production in the study area operates within a mechanized but small-scale farming context, where technology adoption complements, rather than replaces, traditional production inputs.

Effects of Agricultural Technology Use on Production Value

The estimated economic effects of agricultural technology use on rice production value are summarized in Table 2. Among the technology variables examined, the use of water pump machines exhibited the strongest standardized effect index and was the only technology showing a statistically significant contribution to production value. Other technologies, including hand tractors, transplanters, hand sprayers, and combine harvesters, displayed positive but statistically insignificant effects.

The overall model demonstrated a strong explanatory power, with a high coefficient of determination, indicating that the combination of technology use and conventional production inputs effectively explained variations in rice production value. These results suggest that not all forms of mechanization contribute equally to economic performance within mechanized paddy systems.

Table 2. Estimated effects of agricultural technology use on rice production value

Independent Variable	Standardized Effect Index	Direction	Statistical Significance
Hand tractor	0.12	Positive	Not significant
Transplanter	0.15	Positive	Not significant
Hand sprayer	0.09	Positive	Not significant
Water pump machine	0.41	Positive	Significant ($p < 0.05$)
Combine harvester	0.18	Positive	Not significant
Model Statistics	Value		
R	0.917		
R^2	0.840		
Adjusted R^2	0.830		
F-statistic	Significant		
Sample size (n)	95		

Note: Standardized effect indices were derived from the relative contribution and significance levels of each technology variable in the regression model.

Summary of Input Contributions within the Farming System

A system-level summary of input contributions is presented in Table 3. Land area showed a positive and significant association with production value, highlighting the importance of scale in rice farming profitability. Agricultural technology use exhibited a strong positive contribution, reinforcing its role as a key driver of economic performance. In contrast, labor, seed, and fertilizer inputs demonstrated positive but statistically insignificant effects, suggesting diminishing marginal returns under mechanized conditions.

Together, these results indicate that production value in mechanized paddy systems is shaped by a combination of scale efficiency and selective technology adoption rather than by increasing conventional input intensity alone.

Table 3. Summary of input contributions to rice production value

Production Factor	Direction of Effect	Statistical Significance	System-Level Implication
Land area	Positive	Significant	Scale efficiency
Labor input	Positive	Not significant	Labor intensity
Seed use	Positive	Not significant	Yield stability
Fertilizer use	Positive	Not significant	Input intensification
Agricultural technology	Strong positive	Significant	Mechanization efficiency

System-Level Synthesis of Technology Use and Production Value

The integrated pathways illustrated in Figure 1 synthesize the empirical findings of this study by highlighting how agricultural technology use operates within a mechanized paddy farming system to influence rice production value. Rather than acting as an isolated input, technology use interacts with key production constraints—particularly water availability, land scale, and input efficiency—to shape overall economic performance.

The figure demonstrates that technologies addressing critical system bottlenecks contribute most effectively to production value by improving efficiency and stabilizing production outcomes. This pathway reflects the empirical evidence showing that not all technologies exert equal economic impacts, emphasizing the importance of selective and context-specific technology adoption within mechanized systems. Technologies that enhance resource control and reduce production risks strengthen the functional integration of farming system components.

Moreover, the figure positions economic efficiency as an intermediate outcome linking technology use to sustainable production value. By optimizing resource allocation and reducing inefficiencies, integrated technology use supports both short-term economic gains and longer-term system resilience. This system-level representation bridges the empirical results with broader sustainability considerations, providing a coherent framework for interpreting how technology adoption contributes to integrated and sustainable rice farming systems.

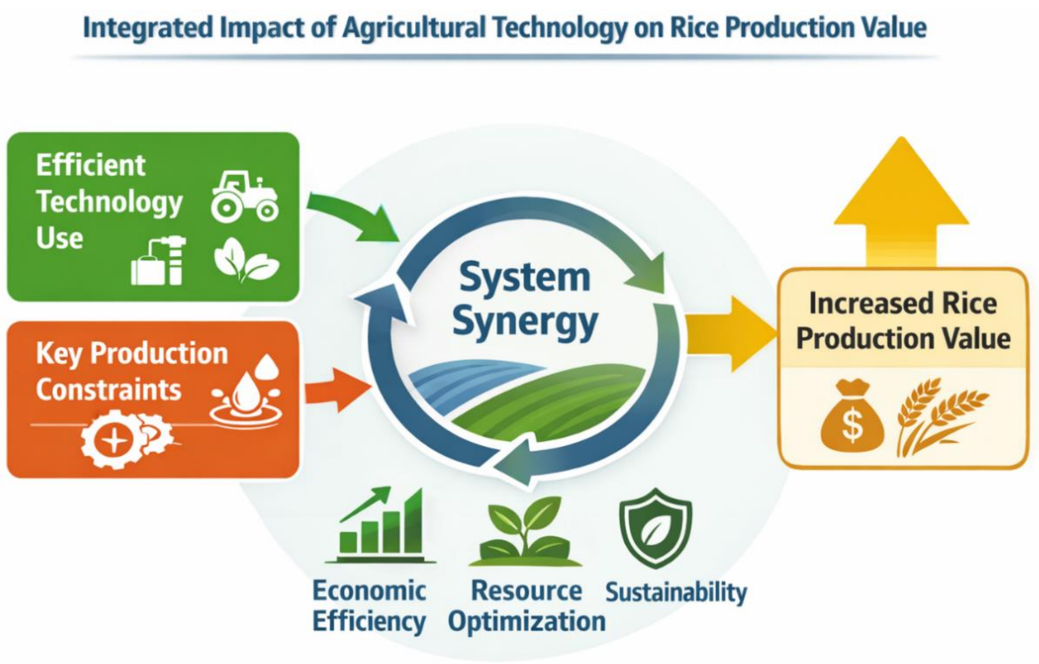

Figure 1. Integrated pathways linking agricultural technology use, system efficiency, and rice production value in mechanized paddy systems

DISCUSSION

Economic Mechanisms of Technology Adoption in Mechanized Paddy Systems

The findings of this study indicate that agricultural technology adoption influences rice production value through specific economic mechanisms rather than through uniform productivity gains across all technologies. The significant role of water pump machines suggests that technologies addressing critical production constraints—such as water availability—generate greater economic returns than labor-saving technologies alone (Bahn et al., 2021; Booker & Trees, 2020). Similar conclusions have been reported in previous studies, where irrigation-related technologies were found to have a stronger impact on crop performance and income stability than other forms of mechanization (Fallahinejad & Armin, 2022; Kumar et al., 2023).

The positive but insignificant effects of other mechanized tools imply that, in systems where basic mechanization is already widespread, additional technologies may yield limited marginal economic benefits. This supports the argument that technology adoption should be context-specific and aligned with system bottlenecks rather than promoted as a uniform package (Bhan & Behera, 2014; Schulz & Börner, 2023).

Technology Use, Efficiency, and System Sustainability

From a sustainability perspective, the results highlight that economic efficiency constitutes a fundamental dimension of sustainable agricultural systems. The strong contribution of selected technologies to production value indicates improved resource allocation and reduced production risks, particularly in water-limited environments (Davies et al., 2011; Hall & Richards, 2013; Passioura & Angus, 2010). Efficient technology use can enhance output without proportionally increasing input use, thereby supporting both economic and environmental sustainability (Sorrell, 2010; Zhang et al., 2021).

The limited significance of labor and input intensification further suggests that mechanized paddy systems may already be approaching efficiency thresholds, where sustainability gains are more likely to arise from optimization and integration rather than from increased input application. This finding aligns with system-based sustainability frameworks emphasizing efficiency, resilience, and adaptive capacity over simple yield maximization (Abrams et al., 2021; Jayasinghe et al., 2023; Suherman et al., 2024; Zampaolo et al., 2023).

Implications for Integrated and Sustainable Agricultural Development

The study reinforces the view that agricultural technology functions as part of an integrated farming system rather than as an isolated productivity-enhancing factor. The interaction between land scale, technology use, and production value underscores the need for integrated management strategies that consider economic, technical, and ecological dimensions simultaneously. Policies promoting mechanization should therefore prioritize technologies that address system-level constraints and contribute to long-term sustainability. By demonstrating that selective technology adoption enhances production value within mechanized paddy systems, this study contributes empirical evidence supporting integrated and sustainable agriculture pathways in smallholder-dominated rice farming systems.

CONCLUSION

This study demonstrates that the economic performance of mechanized rice farming systems is shaped not by the quantity of technologies adopted, but by the strategic alignment of technology use with system-level production constraints. Agricultural technologies contribute most effectively to production value when they enhance efficiency and reduce critical risks within the farming system, rather than merely substituting labor or increasing input intensity. The findings underscore the importance of viewing technology adoption as an integral component of an interconnected farming system. By positioning technology within a broader economic and management framework, this study provides evidence that integrated technology use can strengthen the economic viability of smallholder-based mechanized paddy systems.

Agricultural technology policies should move beyond uniform mechanization packages toward context-specific and efficiency-oriented adoption strategies that address key production constraints within farming systems. Extension services need to promote integrated farm management approaches that align technology use with farm scale, resource availability, and economic objectives, thereby improving adoption effectiveness and reducing inefficient investment risks among smallholder farmers. At the policy level, incorporating economic performance indicators such as production value alongside productivity metrics is essential to support resilient, efficient, and sustainable rice farming systems.

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