Vol. 5 No. 1 (June 2025)
Jurnal Manajemen Agribisnis dan Agroindustri
DOI: 10.25047/jmaa.v5i1.133
e-ISSN: 2807-3789
p-ISSN: 2807-4130

The Impact of Agricultural Machinery Utilization on Production Efficiency and Productivity: A Case Study in Curahwelut Village, Ajung, Jember Regency

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SUBMITTED : JUN 23, 2025	ACCEPTED : JUN 28, 2025	PUBLISHED : JUN 30, 2025

ABSTRACT
This study examines the economic impact of agricultural mechanization on smallholder rice and maize farmers in Curahwelut Village, East Java, Indonesia. Agricultural machinery (alsintan) offers a strategic solution to address labor shortages, rising production costs, and inefficiencies in farm operations. The research employs a quantitative case study approach involving ten purposively selected farmers, all of whom operate on rented land and utilize mechanized equipment at different production stages. Data were collected through structured interviews and analyzed using financial modeling, correlation, and regression techniques. Results show that mechanization enhances productivity, reduces physical labor, and contributes positively to farm profitability. All respondents achieved positive profits, with revenue and net cash flow directly correlated to investment in machinery. Break-even point (BEP), Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI) analyses confirm the economic feasibility of mechanization, with all farmers exceeding BEP thresholds. Regression analysis demonstrates a strong positive relationship between total cost and revenue ($R^2 = 0.749$), indicating that greater input investment yields higher returns. However, structural challenges such as insecure land tenure and aging farmer demographics remain barriers to broader adoption. Findings highlight the need for supportive policies that expand access to credit, improve technology distribution, and promote gender and youth inclusion. Mechanization, when effectively managed, enhances financial sustainability and contributes to rural economic development. This research underscores the importance of tailored mechanization strategies to improve the livelihoods of smallholder farmers in Indonesia.

Keywords — agricultural machinary, production efficiency, productivity

1. Introduction

Agricultural mechanization plays a pivotal role in enhancing efficiency, productivity, and the economic viability of farming systems, particularly within the context of developing countries. The adoption of agricultural machinery—referred to locally in Indonesia as *alsintan*—has emerged as a transformative solution to critical challenges such as labor shortages, rising production costs, and inefficiencies in on-farm operations. In rural settings such as Curahwelut Village, located in Ajung Sub-district, Jember Regency, where rice and maize dominate the cropping landscape, the integration of mechanized practices into conventional agriculture is increasingly essential. Such integration not only boosts farm productivity but also strengthens rural livelihoods and supports the long-term sustainability of the agricultural sector.

The use of agricultural machinery serves to substitute manual labor with tools such as tractors, ploughs, seeders, harvesters, irrigation systems, and equipment for post-harvest handling. This transition significantly enhances operational efficiency, improves accuracy in farming tasks, and lessens the physical workload for farmers. Implementing mechanized technologies contributes to greater agricultural productivity and more efficient resource utilization. It allows smallholder farmers to diversify crop production within a single season and maximize output even on constrained land areas [1]. The widespread adoption of mechanization remains hindered by several structural barriers, including insecure land tenure, limited access to capital, and demographic constraints such as an aging farming population.

The adoption of agricultural mechanization has demonstrated significant impacts across economic, social, and environmental dimensions. Economically, mechanization contributes to increased crop yields, reduced production costs, higher farmer incomes, and more efficient use of labor and time. From a social perspective, while the use of machinery may lead to a reduction in demand for manual labor—potentially causing displacement of agricultural workers—it also improves the overall quality of agricultural output and enhances operational efficiency. Environmentally, precision agriculture technologies associated with mechanization offer the potential to conserve water and reduce input usage. Mechanization may also lead to the overuse of agrochemicals such as pesticides, posing risks to environmental sustainability without proper management [2].

These factors collectively influence the decision-making process of smallholder farmers and may restrict their ability to invest in or benefit fully from technological advancements. Therefore, it is imperative to assess the economic outcomes of mechanized farming at the grassroots level to generate context-specific insights that can guide policy formulation and targeted development programs. Agricultural mechanization is a modernization effort that helps speed up farming by using machines like tractors, milling machines, and threshers. While it improves efficiency and productivity, it also reduces the need for manual labor, especially affecting women who often work in farming. As machines take over these roles, many women lose their jobs and face limited access to agricultural technology[3].

The objective of this study is to examine the impact of agricultural mechanization on production efficiency and farmer productivity in Curahwelut Village. The research evaluates key economic performance indicators—namely, production costs, revenues, profits, break-even points (BEP), net cash flows, and investment feasibility metrics, including Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI). Furthermore, this study seeks to identify patterns of machinery utilization across various crop systems and demographic profiles, thereby contributing to a more nuanced understanding of mechanization's role in advancing smallholder agriculture.

2. Method

This study employed a quantitative case study design, focusing on ten purposively selected smallholder farmers in Curahwelut Village, Ajung Sub-district, Jember Regency, East Java. Selection criteria were based on the farmers' active engagement in rice or maize cultivation and their consistent utilization of agricultural machinery (alsintan) at various stages of production. All respondents operated under rental land tenure arrangements and had practical experience using at least one type of mechanized equipment suited to their respective cropping systems.

Primary data were collected through structured, face-to-face interviews using a comprehensive questionnaire. The instrument captured essential variables such as farmer demographics, machinery types and functions, fixed and variable costs, total production expenses, revenues, and net profits. Additional economic performance indicators, including break-even point (BEP) and net cash flow, were calculated to assess financial sustainability.

To evaluate the economic feasibility of machinery adoption, investment analysis was conducted using standard financial metrics: Net Present Value (NPV), Internal Rate of Return (IRR), and Profitability Index (PI). Furthermore, **Pearson correlation analysis** was employed to determine the strength and direction of relationships between key variables such as costs, revenues, and profits. **Simple linear regression analysis** was applied to assess the influence of total production cost on revenue generation, enabling the quantification of the financial return on mechanization investment.

The collected data were analyzed using descriptive statistics and financial modeling. **All statistical and quantitative analyses, including**

correlation and regression, were conducted using Microsoft Excel and SPSS. These tools facilitated efficient data processing, visualization, and interpretation of results. The findings were synthesized to draw conclusions on the effectiveness, profitability, and sustainability of agricultural machinery utilization among smallholder farmers in the study area.

3. Method

Mechanization in rice farming is most during land preparation, especially among medium- and large-scale farmers. In contrast, crop establishment and maintenance, such as planting and fertilizing, remain mostly manual. Harvesting and post-harvest processes show notable mechanization, particularly through the use of combine harvesters and dryers by larger farmers [4]. The study was conducted by Gudetti et al (2022) showed that mechanization in maize cultivation has proven to be more efficient than conventional methods. The use of tools such as seed cum ferti drill, precision planter, boom sprayer, and combined harvester reduces energy input (36,651 MJ/ha) and labor requirements by up to 37%, without significantly lowering productivity. Although the total output energy is lowe, since it accounts only for grain yield and not the stalk energy productivity and cost efficiency are actually higher under mechanized systems. In addition, mechanization speeds up planting and harvesting, reduces physical strain on farmers, and promotes sustainability by adding organic matter to the soil from crop residues left in the field [5].

The profile of respondent farmers in Curahwelut Village, Ajung Sub-district, Jember Regency, reveals several important characteristics pertinent to the analysis of agricultural mechanization adoption. The sample comprises ten farmers, all of whom are actively engaged in the cultivation of staple food crops, specifically rice and maize. This reflects the agronomic suitability of the region for such commodities and underscores their economic importance within local farming systems. Notably, all respondents operate under a rental land tenure arrangement, indicating a lack of land ownership which may present a structural constraint to long-term investment in agricultural technologies, including farm machinery.

Table 1. Respondent Farmers Profile

No	Name	Age	Land Tenure Status	Commodity	Type of Equipment
1	Roiman	54	Rental	Maize	Hand Tractor
2	Joko	49	Rental	Rice	Rice Thresher
3	Surip	58	Rental	Rice	Rice Milling Machine
4	Slamet	46	Rental	Maize	Cultivator
5	Tuminah	50	Rental	Rice	Two-Wheel Tractor
6	Suroso	52	Rental	Rice	Rice Transplanter
7	Marni	47	Rental	Maize	Sprayer
8	Paijan	60	Rental	Rice	Combine Harvester
9	Sumini	53	Rental	Maize	Maize Sheller
10	Sardi	55	Rental	Rice	Grain Sorter Machine

According to research conducted by Mdoda et al (2023) showed that land ownership has a significant positive impact on agricultural productivity, with landowners achieving higher yields than tenants—particularly on small-sized farms. According to the study in Eastern Cape, South Africa, landowners on small farms increased productivity by 189.4 kg/ha, while tenants only achieved 70 kg/ha. However, 17% of landowners were unable to utilize their land due to lack of funding, water, and farming equipment. Factors such as age, education level, membership in farmer organizations, and access to extension services were positively associated with land ownership, while higher household income and reliance on hired labor negatively influenced it. The study recommends accelerating land reform policies, ensuring gender and youth inclusivity, and providing support services to newly established landowners to enhance agricultural output and food security[6].

Land is a fundamental asset for farmers, as individually owned land, despite potentially lower productivity compared to rented land, yields greater economic benefits. Therefore, to enhance farmers' long term welfare, it is essential to facilitate access to land ownership. Without secure land tenure, farmers are unlikely to fully capture the economic gains derived from improvements in agricultural productivity [7].

The age distribution of the respondents ranges from 46 to 60 years, with a mean age of approximately 52 years. This demographic profile suggests that the farming population is relatively advanced in age, which, while indicative of substantial farming experience, also raises concerns regarding the generational renewal of the agricultural workforce and the potential barriers to technology adoption among older farmers. Despite these challenges, each respondent reported the use of at least one type of agricultural machine, tailored to their respective cropping systems and production phases. Cropping systems that choosed by farmers affect the productivity of crop [8] Intercropping in the land, such as planting another plant in same time and land area could increase the productivity [9]

The type of machinery utilized varies according to crop type. Rice farmers primarily adopt mechanization technologies such as rice transplanters, threshers, milling units, and combine harvesters, which are commonly associated with both production and post-harvest efficiency. Conversely, maize farmers tend to employ hand tractors, cultivators, and shelling machines, primarily to enhance land preparation and harvesting activities. The heterogeneity in machinery use reflects both crop-specific requirements and farmer preferences for mechanization stages.

Furthermore, it is noteworthy that two of the ten respondents are female, which, although a minority, illustrates that women are also participating in mechanized farming activities. This finding contributes to the discourse on gender inclusivity in agricultural development, particularly in relation to access to technology. In conclusion, the profile data suggest that despite limitations in land tenure and the ageing farming population, farmers in Curahwelut Village demonstrate a notable degree of engagement with mechanized agriculture as a strategy to improve efficiency and productivity.

The combined analysis of production costs, revenues, and break-even indicators among farmers in Curahwelut Village reveals significant insights into the economic performance and efficiency of agricultural mechanization. Across the ten respondents, fixed costs ranged from Rp 2,725,000 to Rp 7,200,000, while variable costs varied from Rp 1,125,047 to Rp 3,000,000. The variability in these figures can be attributed to differences in farm size, type of commodity, and the specific machinery used.

Total production costs demonstrate a wide range, from Rp 3,850,047 (Roiman) to Rp 10,200,000 (Paijan), which aligns with their respective levels of mechanization and input utilization. Notably, all farmers achieved positive profits, with the highest recorded by Joko (Rp 33,079,778) and the lowest by Marni and Sardi (Rp 3,800,000 and Rp 8,800,000, respectively). This suggests a consistent economic advantage to mechanization, although the scale of benefit is influenced by crop type and operational scale.

The break-even point (BEP) in physical yield terms varies, ranging from 499.3 kg (Joko) to 1,700 kg (Paijan), reflecting differences in crop pricing and cost structure. In terms of BEP revenue, all farmers surpassed the threshold, affirming profitability. However, a higher BEP revenue indicates a greater sensitivity to price fluctuations and cost control.

Net cash flow values reinforce the profitability patterns, with all respondents maintaining positive cash positions. Paijan recorded the highest net cash flow (Rp 1,800,000), while Marni and Sardi reported the lowest (Rp 500,000). These figures indicate a healthy return on operational investment across the board, suggesting that the adoption of agricultural machinery (alsintan) plays a pivotal role in improving financial liquidity and overall farm sustainability.

Table 2. Cost Details, BEP, and Cash Flow Analysis of Farmers

No	Name	Fixed Cost (Rp)	Variable Cost (Rp)	Total Cost (Rp)	Revenue (Rp)	Profit (Rp)	BEP (kg)	BEP Revenue (Rp)	Net Cash Flow (Rp)
1	Roiman	2,725,000	1,125,047	3,850,047	8,600,000	4,749,953	627	4,429,414	579,367
2	Joko	6,272,222	2,888,000	9,160,222	42,240,000	33,079,778	499.3	9,839,121	678,899
3	Surip	3,966,667	1,185,100	5,151,767	10,890,000	5,738,233	674	5,782,006	630,239
4	Slamet	2,900,000	1,300,000	4,200,000	9,500,000	5,300,000	580	4,730,000	900,000
5	Tuminah	5,500,000	2,600,000	8,100,000	20,000,000	11,900,000	1,200	6,300,000	1,000,000
6	Suroso	6,100,000	2,200,000	8,300,000	18,500,000	10,200,000	1,100	7,100,000	1,100,000
7	Marni	2,850,000	1,150,000	4,000,000	7,800,000	3,800,000	540	3,900,000	500,000
8	Paijan	7,200,000	3,000,000	10,200,000	30,000,000	19,800,000	1,700	8,200,000	1,800,000
9	Sumini	3,300,000	1,400,000	4,700,000	12,000,000	7,300,000	720	4,500,000	1,100,000
10	Sardi	4,800,000	1,900,000	6,700,000	15,500,000	8,800,000	800	5,600,000	500,000

The data underscore the economic viability of mechanized farming among smallholder farmers in Curahwelut Village. While all respondents experienced net financial benefits, the extent of profitability is contingent upon the type of machinery used, crop choice, and input management efficiency. These findings support the strategic promotion of agriculture mechanization to enhance land productivity and income. The study was conducted by Jena et al (2023) indicated that climatic stress appears to have encouraged farmers to shift towards mechanized agriculture. The findings indicate that experiencing climate shocks such as drought, unpredictable rainfall, and flooding has raised the probability of farmers using tractors and electric pumps[10].

Table 3. Investment Feasibility Analysis of Agricultural Machinery (NPV, IRR, PI

No	Name	NPV (Rp)	IRR (%)	PI	Description
1	Roiman	39,706,037	22.53	3.60	Feasible and profitable
2	Joko	12,324,167	12.839	3.52	Feasible and profitable
3	Surip	12,017,058	12.857	2.50	Feasible and profitable
4	Slamet	18,000,000	20.00	3.00	Feasible and profitable
5	Tuminah	16,500,000	18.50	2.90	Feasible and profitable
6	Suroso	14,800,000	17.80	2.70	Feasible and profitable
7	Marni	10,000,000	15.00	2.40	Feasible and profitable
8	Paijan	28,000,000	23.00	3.50	Feasible and profitable
9	Sumini	13,000,000	16.00	2.60	Feasible and profitable
10	Sardi	11,200,000	14.50	2.30	Feasible and profitable

The comprehensive analysis of production costs, revenue, and break-even indicators among farmers in Curahwelut Village reveals critical insights into the economic performance of agricultural mechanization. Fixed costs incurred by the respondents ranged from Rp 2,725,000 to Rp 7,200,000, while variable costs were between Rp 1,125,047 and Rp 3,000,000. These variations are primarily attributable to differences in farm size, crop type, and the specific types of machinery employed.

Total production costs—comprising both fixed and variable components—exhibited substantial variability, spanning from Rp 3,850,047 (Roiman) to Rp 10,200,000 (Paijan). This range aligns with the scale of mechanization and input intensity across farms. All respondents recorded positive net profits, with Joko achieving the highest (Rp 33,079,778) and Marni and Sardi recording the lowest (Rp 3,800,000 and Rp 8,800,000, respectively). These results indicate that the adoption of agricultural machinery contributes positively to farm profitability, although the magnitude of benefit is contingent upon crop characteristics and operational efficiency.

The BEP analysis further supports the economic viability of mechanization. BEP values in terms of output ranged from 499.3 kg to 1,700 kg, while BEP revenue spanned from Rp 3,900,000 to Rp 9,839,121. The fact that all farmers exceeded their BEP levels confirms that their farming activities are financially sustainable. Nonetheless, higher BEP revenue values suggest greater sensitivity to market price fluctuations and input cost variability.

Net cash flow analysis corroborates the profitability findings, with all farmers maintaining a positive cash position. The highest net cash flow was observed in Paijan (Rp 1,800,000), while the lowest was recorded by Marni and Sardi (Rp 500,000 each). These outcomes underscore the role of mechanization in enhancing liquidity and ensuring financial resilience among smallholder farmers.

The economic feasibility of mechanized agriculture, respondents benefited financially, the degree of profitability varied based on the type of machinery utilized, crop cultivated, and efficiency of input management. These findings highlight the strategic importance of promoting mechanization as a means to bolster productivity, economic sustainability, and income security among rural farming communities.

Farm mechanization had a positive and significant effect at the 5% level on farmers' gross income. This is attributed to mechanization reducing the physical labor required from both humans and draft animals, while also increasing cropping intensity, improving precision and timing in the use of crop inputs, and minimizing losses during various stages of crop production[11].

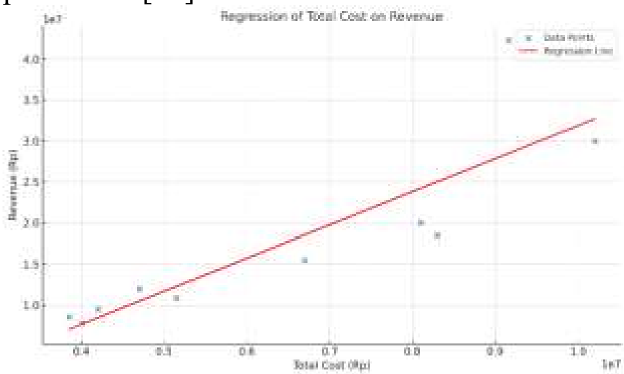

Figure 1. Regression of Total Cost Revenue

The linear regression model further reinforces this relationship. With an R-squared value of 0.749, the model explains approximately 74.9% of the variance in revenue, indicating a relatively strong model fit. The regression coefficient for total cost is 4.035, implying that for every additional Rp 1,000,000 in total expenditure, revenue increases by an estimated Rp 4,035,000. The intercept value of –Rp 8,469,000, though not directly interpretable in economic terms, reflects the starting point of the regression equation. The statistical significance of the total cost variable ($p = 0.001$) confirms its robust impact on revenue generation.

These statistical outputs highlight the efficiency and economic justification for the adoption of alsintan in smallholder agricultural systems. The strong positive relationship between cost and revenue implies that investment in machinery and production inputs, when managed effectively, can lead to substantial improvements in income. Furthermore, the near-perfect correlation between revenue and profit emphasizes that profitability is predominantly driven by the ability to optimize output, which in turn depends on the efficient deployment of mechanization technologies.

Based on the research conducted by Chairunnisya, between 2011 and 2015, the distribution of agricultural machinery across provinces was moderate, with East Java and Central Java receiving the largest share. The average planted area in these provinces remained relatively stable. However, from 2016 to 2019, there was a significant increase in machinery distribution, particularly in South Sulawesi and Central Java. Despite this rise, the average planted area in most provinces changed only slightly. From 2020 to 2023, the number of machinery units distributed declined sharply, accompanied by a decrease in the average planted area across all provinces, with the most notable drops in East Java and South Sumatra [12].

Table 3. Pearson Correlation Between Variables

Variable	Total Cost	Revenue	Profit
Fixed Cost	0.99	0.84	0.76
Variable Cost	0.98	0.90	0.84
Total Cost	1.00	0.87	0.79
Revenue	0.87	1.00	0.99
Profit	0.79	0.99	1.00

The results of the correlation and regression analyses provide substantial insights into the relationship between production costs, revenue, and profitability in the context of smallholder farmers utilizing agricultural machinery (alsintan) in Curahwelut Village.

The Pearson correlation matrix indicates a strong positive relationship between total cost and revenue (r = 0.87), suggesting that increased investment in production inputs and mechanization tends to be associated with higher financial returns. Additionally, profit exhibits an exceptionally high correlation with revenue (r = 0.99), underscoring the direct influence of effective income generation on overall profitability. Both fixed costs (r = 0.84) and variable costs (r = 0.90) demonstrate notable correlations with revenue, indicating that each cost component significantly contributes to the production outcome. These findings reflect the importance of both capital-intensive and operational expenditures in determining economic performance.

The study was conducted by Khanikar (2022) showed the level of mechanization in summer paddy cultivation in the Brahmaputra Valley is still moderate, with most farmers using machinery only in early stages such as land preparation and irrigation. The majority of equipment is rented due to limited income and small landholdings. The average capital intensity is Rs 26,439.57 per hectare, with the highest expenses on irrigation and tractors. Factors influencing mechanization and capital use include land size, income, farming experience, education, and access to credit. However, access to formal credit remains low. Policies are needed to expand credit access, provide subsidized machinery, and offer technical training to improve agricultural productivity [13].

4. Conclusion

The Pearson correlation results reveal strong positive relationships between total cost and revenue (r = 0.87), as well as between revenue and profit (r = 0.99), indicating that effective cost management and mechanization directly influence profitability. Moreover, regression analysis confirms a statistically significant linear relationship between total production cost and revenue ($R^2 = 0.749$, $p = 0.001$), suggesting that increased investment in mechanization is likely to yield higher financial returns.

Despite structural limitations such as land rental status and an aging farmer demographic, the findings affirm the economic viability of mechanization. The investment appraisal through NPV, IRR, and PI metrics further supports the feasibility and profitability of alsintan use in rice and maize farming systems.

Agricultural mechanization not only improves farm productivity and income security but also contributes to the long-term sustainability of smallholder agriculture. These results support the need for continued policy support, inclusive access to machinery, and targeted financial assistance to scale mechanization in rural Indonesia.

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