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Agricultural Modernization and Mechanization as a Strategy to Increase National Food Production

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Abstract:
This study analyzes agricultural modernization and mechanization as strategies for increasing national food production in Indonesia, with particular attention to implementation dynamics and farmer responses to technological change. The study employs a descriptive qualitative approach with policy implementation and socio-technical analysis. Data were collected through document analysis of government policy documents, BPS Agricultural Census data, Ministry of Agriculture reports, academic literature, and relevant studies on mechanization, precision agriculture, farmer adoption, and food production policy. The findings show that mechanization has strong potential to improve production efficiency by accelerating land preparation, planting, harvesting, irrigation support, and post-harvest handling. However, the effectiveness of mechanization depends on technology suitability, farmer access, operator availability, maintenance capacity, financing, and institutional support. The study also finds that smallholder farmers face specific barriers to mechanization because of fragmented landholdings, limited capital, high rental costs, and unequal access to machinery services. Farmer response is shaped by perceived usefulness, perceived cost, land size, labor availability, trust in technology, and the role of farmer institutions. The novelty of this study lies in framing agricultural mechanization as a socio-technical transformation rather than a purely technical production strategy. The study concludes that mechanization can strengthen national food production only when it is inclusive, locally adaptive, and supported by farmer-centered service institutions.

Keywords: agricultural modernization; mechanization; food production; farmer response; socio-technical transformation; smallholder farmers; Indonesia.

1. Introduction

Agricultural modernization has become an important agenda in Indonesia's food security policy because national food production increasingly faces structural challenges related to land conversion, labor scarcity, aging farmers, climate variability, production inefficiency, and post-harvest losses. In this context, mechanization is promoted as one of the main strategies to increase production efficiency, accelerate land preparation, improve planting and harvesting processes, reduce labor dependence, and strengthen national food production capacity. Modernization does not only refer to the use of agricultural machinery, but also includes changes in production systems, farmer institutions, cultivation technology, input management, irrigation support, post-harvest handling, and digital-based agricultural services. Therefore, agricultural modernization should be understood as a transformation of the food production system from labor-intensive and traditional methods toward more efficient, technology-based, and institutionally supported farming.

The urgency of agricultural modernization can be seen from the structure of Indonesia's agricultural labor and land ownership. The 2023 Agricultural Census reported that Indonesia had 25.12 million agricultural business households and 27.37 million farmer households, with food crops being the most widely cultivated subsector by 15.55 million households (BPS, 2023a). BPS also recorded 27.80 million farmers using agricultural land, of which 17.25 million were smallholder farmers cultivating less than 0.5 hectare of agricultural land (BPS, 2023b). This structure shows that Indonesian agriculture is still dominated by small-scale farming, which affects the adoption of mechanization because machinery use often requires sufficient land scale, farmer group organization, service providers, or collective management. At the same time, BPS recorded 6.18 million millennial farmers aged 19–39 years, or around 21.93 percent of all

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farmers, indicating that generational regeneration remains limited (BPS, 2023c). These conditions strengthen the need for modernization policies that are not only technology-oriented, but also responsive to the social structure of farmers.

Mechanization is expected to address several technical problems in food production. In rice farming, agricultural machinery such as hand tractors, four-wheel tractors, rice transplanters, water pumps, drones, combine harvesters, dryers, and milling equipment can improve production efficiency from land preparation to post-harvest handling. Indrayanti et al. (2024) found that modern rice farming using agricultural machinery can produce higher yields than conventional farming because the use of combine harvesters reduces harvesting damage and field losses. Their study also showed that modern farming requires fewer labor days than conventional farming, although investment costs remain relatively high and many farmers still depend on government assistance to access machinery (Indrayanti et al., 2024). This indicates that mechanization has production benefits, but its effectiveness depends on affordability, operator skills, maintenance capacity, and access mechanisms.

The government has continued to promote agricultural mechanization through the distribution of agricultural machinery, institutional strengthening, and food self-sufficiency programs. In 2025, the Ministry of Agriculture emphasized that mechanization is an urgent requirement in modern agriculture, particularly in regions with wide agricultural land and limited labor availability (Kementerian Pertanian, 2025a). In Tanah Laut Regency, for example, the government distributed 693 units of pre-harvest agricultural machinery, including two-wheel and four-wheel tractors, crawler tractors, rice transplanters, water pumps, and hand sprayers, to support land processing efficiency and productivity improvement (Kementerian Pertanian, 2025a). The same policy direction was also reflected in the 2026 food security budget proposal, in which production-side support was directed toward agricultural machinery, fertilizer subsidies, dams, irrigation networks, superior seeds, new rice field development, and strategic agricultural areas (Kementerian Pertanian, 2025b). Although these programs show strong state support for modernization, the key issue is whether mechanization can be implemented effectively by farmers with different land sizes, capital capacity, skills, and institutional readiness.

The implementation of agricultural mechanization is not always linear because farmers respond to technology based on economic, social, technical, and cultural considerations. Farmers may accept machinery when it reduces labor costs, shortens working time, improves yields, and provides clear economic benefits. However, farmers may resist or underuse machinery when rental costs are high, machines are not suitable for local land conditions, operators are unavailable, maintenance is difficult, or machine ownership is controlled by certain groups. Smallholder farmers may face additional barriers because fragmented landholdings and limited capital make individual ownership of machinery inefficient. Therefore, collective mechanisms such as farmer groups, cooperatives, *Unit Pelayanan Jasa Alsintan* (UPJA), *Gapoktan*, and machinery service providers become important in ensuring that mechanization can be accessed by small farmers rather than only by larger producers.

Modernization also raises questions about labor transformation in rural areas. Mechanization can reduce dependence on manual labor and increase efficiency, but it may also change employment patterns for farm workers who previously depended on land preparation, planting, harvesting, and post-harvest labor. The adoption of combine harvesters, for instance, may reduce the need for manual harvesting labor, while increasing demand for machine operators, mechanics, service managers, and post-harvest technicians. This means that agricultural modernization should be accompanied by skills development, vocational training, youth engagement, and rural service-sector development. Without human resource transformation, mechanization may create technological dependency without improving local capacity.

Previous studies have discussed agricultural mechanization, technology adoption, and modern farming from several perspectives. Indrayanti et al. (2024) showed that modern rice farming using agricultural machinery can increase production and reduce labor use, but also requires stronger machinery management and operator capacity. Herdiansyah et al. (2023) emphasized that mechanization and precision agriculture can improve sustainability and efficiency when supported by appropriate technology, farmer readiness, and institutional adaptation. Studies on smart farming and Agriculture 4.0 also indicate that digital technologies, sensors, artificial intelligence, drones, and data-based decision-making can strengthen

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productivity and resource efficiency, but their adoption depends on farmer literacy, infrastructure, financing, and compatibility with local farming systems (Babar & Akan, 2024; Gyamfi et al., 2024). These studies show that modernization is not only a technical issue, but also an institutional and social process.

The research gap lies in the limited analysis of agricultural modernization and mechanization as an implementation issue that includes farmer response to technological change. Existing discussions often emphasize the technical benefits of machinery, production efficiency, or government assistance, while less attention is given to how farmers actually respond to mechanization in relation to land size, labor availability, capital access, service institutions, and perceived usefulness. This article offers a novel contribution by examining agricultural modernization not only as a national production strategy, but also as a socio-technical transformation that requires farmer acceptance, institutional support, and equitable access to technology. The study argues that mechanization will strengthen national food production only when it is aligned with farmer needs, local agroecological conditions, machinery service systems, and inclusive rural institutions. Accordingly, this study aims to analyze the implementation of agricultural modernization and mechanization in Indonesia and farmer responses to technological changes in food production systems.

2. Methodology

This study employs a descriptive qualitative approach with a policy implementation and socio-technical analysis design. This approach is used because the study examines agricultural modernization and mechanization not only as technical interventions to increase food production, but also as policy processes that involve farmer acceptance, institutional readiness, access to machinery, labor transformation, and adaptation to local farming conditions. The qualitative approach enables the study to analyze how mechanization policies are implemented in the field and how farmers respond to technological changes in food production systems. Rather than measuring the impact of mechanization through quantitative productivity modeling, this study focuses on interpreting the implementation dynamics of agricultural modernization and the social, institutional, and technical factors that influence farmer adoption.

The object of this study is the implementation of agricultural modernization and mechanization policy in Indonesia, particularly in relation to food crop production. The analysis focuses on the use of agricultural machinery and production-support technologies, including tractors, rice transplanters, water pumps, combine harvesters, dryers, milling equipment, drones, and digital-based agricultural services. These technologies are examined as part of the government's broader strategy to improve production efficiency, reduce labor constraints, accelerate planting and harvesting processes, minimize post-harvest losses, and strengthen national food production capacity. The study also examines how these modernization instruments interact with farmer characteristics, landholding structure, farmer groups, machinery service providers, and local institutional capacity.

The data used in this study consist of primary and secondary data. Primary data may be obtained through semi-structured interviews with farmers, farmer group leaders, agricultural extension officers, machinery service unit managers, local agricultural agency officials, machinery operators, rural youth farmers, and agricultural technology experts. These interviews are directed at understanding farmer perceptions of mechanization, access to machinery, operational constraints, cost considerations, changes in labor use, technology acceptance, and the role of farmer institutions in supporting mechanization. Secondary data are collected through document studies, including government policy documents, BPS Agricultural Census data, Ministry of Agriculture reports, agricultural machinery program documents, official statistical publications, academic articles, and previous studies on mechanization, agricultural modernization, technology adoption, and food production policy.

Data collection is conducted through document analysis, semi-structured interviews, and limited field observation where possible. Document analysis is used to examine the policy framework of agricultural modernization, government support for agricultural machinery, farmer demographic data, landholding structure, and previous evidence on mechanization outcomes. Semi-structured interviews are used to obtain empirical information from actors involved in mechanization implementation, especially farmers and local agricultural institutions. Field observation may be conducted in selected food crop production areas, farmer group locations, machinery service units, rice fields using mechanized cultivation, or post-harvest facilities

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to understand how agricultural machinery is used in practice. This combination of techniques enables the study to compare formal modernization policy with actual farmer-level implementation.

The data are analyzed using interactive qualitative analysis, consisting of data reduction, data classification, thematic interpretation, and conclusion drawing. Data reduction is carried out by selecting information relevant to agricultural modernization, mechanization implementation, farmer response, machinery access, institutional support, labor transformation, and production efficiency. Data classification is conducted by grouping the findings into several analytical categories: policy design, machinery distribution, technology access, farmer acceptance, operational constraints, institutional support, labor impact, production efficiency, and sustainability. Thematic interpretation is then conducted by linking these categories with the concepts of policy implementation, socio-technical transition, and agricultural innovation adoption. The final stage draws conclusions regarding whether modernization and mechanization have functioned as effective strategies for increasing national food production or whether their implementation remains constrained by social and institutional factors.

The analytical framework of this study is built on five main dimensions. The first dimension is policy implementation, which refers to how agricultural modernization programs are translated into machinery distribution, farmer assistance, extension services, and production-support mechanisms. The second dimension is technology accessibility, which examines whether farmers can access machinery through ownership, rental systems, farmer groups, cooperatives, or machinery service units. The third dimension is farmer response, which assesses farmer acceptance, perceived usefulness, perceived cost, operational readiness, and willingness to adopt mechanized production systems. The fourth dimension is institutional support, which analyzes the role of farmer groups, extension workers, local governments, machinery operators, and service providers in sustaining mechanization. The fifth dimension is production and livelihood impact, which examines whether mechanization improves efficiency, reduces labor constraints, increases production potential, and affects rural labor patterns.

To strengthen the validity of the analysis, this study applies source triangulation by comparing data from official statistics, policy documents, academic literature, stakeholder interviews, and field observations. Triangulation is important because mechanization policy may be interpreted differently by policymakers, extension officers, machinery service providers, and farmers. Government documents may emphasize machinery distribution and production targets, while farmers may highlight practical issues such as machine suitability, rental cost, operator availability, maintenance, and land fragmentation. By comparing these perspectives, the study can provide a more balanced understanding of agricultural modernization as a policy and social transformation process. Through this methodological framework, the research seeks to explain how mechanization contributes to national food production and how farmer response determines the success of agricultural modernization in Indonesia.

3. Results and Discussions

1) Agricultural Mechanization as a Production Efficiency Strategy

The findings show that agricultural mechanization has become one of the main instruments in Indonesia's food production strategy because it is expected to address labor scarcity, accelerate cultivation processes, and reduce inefficiencies in land preparation, planting, harvesting, and post-harvest handling. Mechanization is particularly relevant in rice-based food production because rice farming requires timely operations across the production cycle. Delays in land preparation, planting, irrigation, harvesting, or drying may reduce yields and increase production losses. In this context, machinery such as two-wheel tractors, four-wheel tractors, rice transplanters, water pumps, combine harvesters, dryers, and milling equipment functions not only as technical equipment, but also as part of a broader production governance system.

The urgency of mechanization is strengthened by the structure of Indonesian agriculture, which remains dominated by small-scale farming. The 2023 Agricultural Census showed that Indonesia had more than 27 million farmers using agricultural land, while more than 17 million of them were categorized as smallholder farmers cultivating less than 0.5 hectare of land (BPS, 2023). This condition creates a paradox for mechanization policy. On the one hand, mechanization is needed to improve efficiency and reduce

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dependence on manual labor. On the other hand, small and fragmented landholdings make individual machine ownership economically inefficient for many farmers. Therefore, the success of mechanization depends not only on the distribution of machinery, but also on collective access models such as farmer groups, cooperatives, machinery service units, and rental-based mechanization services.

Government support for mechanization has been implemented through the distribution of agricultural machinery and the strengthening of food production programs. In 2025, the Ministry of Agriculture emphasized that mechanization is an urgent need in modern agriculture, particularly in regions with wide agricultural land and limited labor availability (Kementerian Pertanian, 2025a). The distribution of 693 pre-harvest agricultural machinery units in Tanah Laut Regency, including tractors, crawler tractors, rice transplanters, water pumps, and hand sprayers, illustrates the government's attempt to accelerate land processing and increase production efficiency (Kementerian Pertanian, 2025a). This policy reflects a production-oriented modernization strategy that seeks to increase planting intensity, shorten the cultivation cycle, and support food self-sufficiency.

However, the effectiveness of mechanization cannot be measured only by the number of machines distributed. Machinery distribution may increase production efficiency only if the machines are suitable for local agroecological conditions, available when farmers need them, operated by skilled users, and supported by maintenance services. In many rural areas, mechanization faces practical constraints such as limited operators, machine damage, spare-part scarcity, high rental costs, weak service institutions, and uneven access among farmers. These constraints indicate that mechanization requires an institutional ecosystem, not merely equipment provision. Without proper management, distributed machinery may become underused, damaged, or captured by certain farmer groups with stronger access to local institutions.

The production benefits of mechanization are most visible when machinery is integrated across the production chain. Tractors can accelerate land preparation, transplanters can improve planting uniformity, water pumps can support irrigation during dry periods, combine harvesters can reduce harvesting losses, and dryers can improve post-harvest quality. Studies on mechanized rice farming show that the use of modern agricultural machinery can reduce labor use, shorten working time, and improve efficiency compared with conventional methods (Indrayanti et al., 2024; Herdiansyah et al., 2023). Nevertheless, mechanization produces optimal results only when it is connected with proper cultivation practices, input management, irrigation availability, and post-harvest systems. This means that mechanization should be understood as a system intervention rather than a single technological solution.

2) Farmer Response to Technological Change

The second finding shows that farmer response is a decisive factor in the success of agricultural modernization. Farmers do not automatically adopt technology simply because machinery is available. Their response is shaped by perceived usefulness, perceived cost, land size, risk perception, labor availability, access to operators, trust in technology, and previous experience with government programs. Farmers tend to accept mechanization when they see clear benefits, such as faster land preparation, lower labor costs, reduced harvest losses, and better production timing. However, adoption becomes slower when machines are considered expensive, difficult to operate, unsuitable for local land conditions, or controlled by actors outside the farmer community.

Smallholder farmers face specific barriers in adopting mechanization. Because many farmers cultivate small and fragmented plots, the economic logic of mechanization is different from that of large-scale farming. Large machinery may not be suitable for narrow plots, irregular field shapes, or areas with poor road access. In such cases, farmers may prefer manual labor or smaller-scale machinery that is more compatible with local conditions. This shows that mechanization policy should not apply a uniform technology model across all regions. Technology must be adapted to land structure, cropping patterns, irrigation systems, topography, and farmer capacity.

The role of farmer institutions is central in shaping technology adoption. Farmer groups, *Gapoktan*, cooperatives, and *Unit Pelayanan Jasa Alsintan* can reduce the cost burden of mechanization by providing shared access to machinery. These institutions can coordinate rental schedules, manage machine maintenance, train operators, and ensure that small farmers can access machinery during critical production

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periods. Without such institutions, machinery may be accessible only to larger farmers or groups with stronger social and political connections. This would create inequality in technological access and weaken the inclusive objective of agricultural modernization.

Farmer response is also influenced by labor dynamics in rural areas. Mechanization is often promoted as a solution to declining agricultural labor availability and the aging farmer population. The 2023 Agricultural Census recorded only around 6.18 million millennial farmers aged 19–39 years, indicating that farmer regeneration remains a major challenge (BPS, 2023). In this context, mechanization may attract younger farmers if it is connected with modern, efficient, and technology-based farming. However, if modernization remains limited to machine distribution without digital literacy, technical training, business models, and market support, it may not be sufficient to make agriculture attractive to younger generations. Mechanization must therefore be linked to broader rural transformation, including skill development, service entrepreneurship, and agricultural innovation.

The adoption of mechanization also changes the social structure of agricultural work. On one side, machinery reduces dependence on manual labor and helps farmers manage labor shortages during peak seasons. On the other side, it may reduce employment opportunities for agricultural laborers involved in planting, harvesting, threshing, and post-harvest activities. This does not necessarily mean that mechanization is harmful, but it requires labor transition policies. Rural workers need opportunities to become machine operators, mechanics, service managers, agricultural technicians, or actors in post-harvest and logistics services. If labor transformation is not prepared, mechanization may improve production efficiency while creating social adjustment problems in rural labor markets.

3) Institutional and Operational Challenges in Mechanization Implementation

The third finding indicates that the main challenge of mechanization lies in institutional and operational sustainability. Government programs often focus on machinery procurement and distribution, but the long-term usefulness of mechanization depends on how machines are managed after distribution. Machines require operators, fuel, spare parts, maintenance, storage, scheduling, and financial management. If these elements are not available, machinery assistance may not produce sustained productivity improvement. This is why mechanization policy must shift from an asset-distribution approach to a service-system approach.

A service-system approach means that farmers do not necessarily need to own machines individually. Instead, they need reliable access to machinery services at the right time and at affordable prices. This approach is more suitable for Indonesia's smallholder structure because shared machinery services can reduce investment costs and improve machine utilization rates. Winarno et al. (2025) emphasize that agricultural mechanization potential in Indonesia is strongly related to the capacity to overcome disparities in adoption among smallholder farmers. This supports the argument that mechanization should be organized through service providers, cooperatives, farmer groups, and local enterprises rather than through fragmented individual ownership.

Another operational issue is technology suitability. Mechanization policy must consider whether machines match local agroecological conditions. For example, heavy machinery may be less suitable for wet, soft, or peat-based fields, while large combine harvesters may be difficult to operate in small and fragmented plots. Rice transplanters require specific seedling preparation and field conditions that may not be familiar to all farmers. Drones and digital technologies require connectivity, technical literacy, and maintenance capacity. These examples show that modernization should not be treated as simple technology transfer. It requires adaptation, training, and local experimentation.

Extension services play an important role in bridging technology and farmer adoption. Agricultural extension officers can help farmers understand how machines work, when to use them, how to calculate economic benefits, and how to integrate mechanization with cultivation practices. Extension services also help reduce uncertainty because farmers often hesitate to adopt technology when they do not fully understand operational risks or expected benefits. In the context of mechanization, extension should not only provide general agricultural advice, but also technical guidance on machine operation, maintenance, service management, and cost-benefit calculation.

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Financing is another important factor. Many farmers cannot afford machinery ownership, and even rental costs may be burdensome during periods of low income or uncertain harvest. Mechanization programs should therefore be supported by flexible financing schemes, machinery rental systems, subsidized service models, and credit access for farmer institutions or machinery service providers. Without financing support, mechanization may remain dependent on government aid and fail to develop into a sustainable local service economy. A sustainable mechanization ecosystem requires private participation, cooperative management, local entrepreneurship, and government facilitation.

4) Mechanization, Production Growth, and Inclusive Agricultural Modernization

The overall findings indicate that mechanization has strong potential to increase national food production, but its effectiveness depends on inclusive implementation. Mechanization contributes to production growth by improving timeliness, reducing labor bottlenecks, minimizing post-harvest losses, and supporting more efficient cultivation. In rice farming, timely land preparation and harvesting are essential because delays can reduce productivity and increase losses. Combine harvesters, dryers, and milling technologies are especially important because production improvement is not determined only by field yield, but also by how much harvest can be saved, processed, and maintained in good quality.

However, mechanization should not be seen as a stand-alone strategy. National food production cannot be increased sustainably through machinery alone if land protection, irrigation, seeds, fertilizer, extension, climate adaptation, farmer institutions, and market access remain weak. Mechanization must be integrated with broader agricultural modernization. This includes digital farming, climate-smart agriculture, post-harvest technology, supply-chain improvement, farmer regeneration, and rural service development. Herdiansyah et al. (2023) argue that precision agriculture and mechanization can support sustainable rice farming when they are aligned with farmer readiness and local farming systems. This means that modernization must be socio-technical, not merely technological.

The inclusiveness of mechanization is also crucial. If machinery access is concentrated among larger farmers, politically connected groups, or better-off regions, mechanization may widen inequality within the farming sector. Small farmers may remain dependent on manual labor or expensive rental services, while larger farmers benefit from productivity gains. To avoid this, mechanization policy must prioritize equitable access through farmer groups, cooperatives, UPJA, local service providers, and transparent machinery allocation mechanisms. The high number of smallholder farmers in Indonesia makes inclusive access a central requirement for modernization policy.

Farmer response should become a key indicator in evaluating mechanization policy. A program may distribute many machines, but if farmers do not use them, do not trust them, cannot afford them, or consider them unsuitable, the program will not produce meaningful transformation. Evaluation should therefore include machine utilization rates, farmer satisfaction, cost savings, labor changes, yield effects, repair frequency, operator availability, and access among small farmers. This would shift the evaluation of modernization policy from input-based measurement to outcome-based and farmer-centered assessment.

In conclusion, the implementation of agricultural modernization and mechanization in Indonesia shows both opportunity and constraint. Mechanization can increase production efficiency and support national food production, but it requires institutional readiness, technology suitability, farmer acceptance, financing mechanisms, extension support, and inclusive access. The novelty of this discussion lies in framing mechanization as a socio-technical transformation rather than simply a production technology. Modernization will strengthen national food production only when farmers are not treated as passive recipients of machinery, but as active actors whose needs, constraints, and responses determine the success of technological change.

4. Conclusion

This study concludes that agricultural modernization and mechanization are important strategies for increasing national food production in Indonesia, particularly in responding to labor scarcity, land fragmentation, aging farmers, and the need for more efficient food production systems. Mechanization can accelerate land preparation, planting, irrigation support, harvesting, and post-harvest handling. It can also

reduce dependence on manual labor, shorten production time, reduce harvest losses, and support higher productivity. However, the findings show that mechanization cannot be understood merely as the distribution of agricultural machinery. Its effectiveness depends on whether the technology is suitable for local agroecological conditions, accessible to smallholder farmers, supported by operators and maintenance systems, and integrated with farmer institutions.

The main finding of this study is that agricultural mechanization in Indonesia faces a gap between policy ambition and farmer-level implementation. Government programs have supported modernization through machinery distribution and production-support policies, but many farmers still face constraints related to land size, rental costs, operator availability, machine maintenance, fragmented plots, and limited institutional capacity. Smallholder farmers are particularly vulnerable to exclusion because individual machine ownership is often economically inefficient for farms smaller than 0.5 hectare. Therefore, mechanization policy requires collective access mechanisms through farmer groups, cooperatives, *Gapoktan*, *Unit Pelayanan Jasa Alsintan*, and local machinery service providers.

This study also finds that farmer response is a decisive factor in determining the success of agricultural modernization. Farmers tend to adopt mechanization when they perceive clear benefits, such as lower labor costs, faster operations, reduced harvest losses, and better production timing. However, farmers may resist or underuse technology when machines are not suitable for local land conditions, costs are too high, operators are unavailable, or the benefits are uncertain. This indicates that modernization should be implemented as a socio-technical transformation, not merely as a technological intervention. Farmers should not be treated as passive recipients of machinery, but as active actors whose perceptions, capacities, and institutional environments shape technology adoption.

The novelty of this study lies in framing agricultural mechanization as a socio-technical policy process that links production efficiency with farmer acceptance and institutional readiness. Previous studies have generally emphasized the technical benefits of mechanization, while this study highlights that modernization will strengthen national food production only when it is inclusive, locally adaptive, and institutionally supported. The implication is that future policy should move from machinery distribution toward machinery service-system development. This includes strengthening UPJA, farmer cooperatives, operator training, maintenance networks, financing schemes, technology suitability assessment, and farmer-centered evaluation. Further research should conduct field-based comparative studies across food-producing regions to measure machine utilization rates, farmer satisfaction, production outcomes, labor transformation, and the inclusiveness of mechanization access among smallholders.

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