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Optimizing Agricultural Mechanization to Enhance the Efficiency and Productivity of Farming In Indonesia: A Review

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ABSTRACT

Agricultural mechanization has emerged as a cornerstone of modernizing the agricultural sector in Indonesia, playing a pivotal role in enhancing productivity and efficiency. The growing population and the necessity for increased agricultural output have driven the adoption of mechanization to overcome challenges such as labor shortages and the adverse effects of climate anomalies. The introduction of agricultural equipment follows a selective principle by considering the local area's socioeconomic conditions. Future agricultural mechanization utilizes technologies based on weather analysis, soil sensor information, and satellite and drone imaging that can increase agricultural productivity. Precision agriculture innovation to improve the accuracy of farm business management is carried out by utilizing sensor systems, drones, remote sensing, digital technology, and the Internet of Things (IoT) to collect, process, and present data that smart farming systems will use. Integrated information system innovations for the supply chain are designed to bridge farmers, distributors, markets, and end buyers by utilizing mobile applications. The traditional to modern transition process and the implementation of smart digital farming require mentoring and field learning in the agricultural process from upstream to downstream. This review provides a comprehensive overview of the development, challenges, opportunities, and prospects of agricultural mechanization in Indonesia, offering insights into how these efforts can support the country's economic growth and food security. Materials were prepared from various sources, including development planning documentation program reports, evaluation, and critical analysis of different research results.

1. INTRODUCTION

1.1. Research Background

Agricultural development is projected to sustain favorable economic growth by implementing policies to enhance productivity and added value, promote sustainable investment, improve the labor market, and increase the quality of human resources. Future medium-term agricultural development must contend with constantly shifting domestic and global strategic environments. Because it produces food, cattle feed, and bioenergy, agriculture plays a vital role in human life. To achieve food security, boost competitiveness, absorb workers, and reduce poverty, agriculture plays a critical and strategic role in the country's economy. Furthermore, to improve the nation's foreign exchange profits by fostering the expansion of the agro-industry downstream and speeding the export of agricultural commodities [1].

Agricultural mechanization has become one of the essential pillars in the modernization of the agricultural sector in Indonesia. Along with the rapid population growth and the need for increased agricultural productivity, mechanization has played a crucial role in improving the efficiency and effectiveness of agricultural production. Moreover, there are labor limitations and natural disaster disturbances due to the influence of climate anomalies. The mechanization level in Indonesia grew from 1968, which was only 1.173 HP/ha, to 1.68 in 2018. Indonesia's mechanization level is indeed higher when compared to Vietnam, Cambodia, and the Philippines [2]. However, the mechanization level in Indonesia is still below Thailand and Malaysia, so there needs to be a strategy to improve it [3].

In recent decades, information and communication technology development has paved the way for further transformation in agricultural mechanization. The concept of precision agriculture and agricultural digitalization is gaining attention as a solution to overcome various

challenges faced by the traditional agricultural sector. Precision agriculture, which uses advanced technologies such as sensors, GPS systems, and extensive data analysis, allows farmers to manage their land more precisely, efficiently, and environmentally friendly. Meanwhile, agricultural digitalization facilitates access to information, supply chain management, and more effective marketing of agricultural products.

Agricultural mechanization is anticipated to enhance the efficacy of human labor, elevate the level and quality of life for farmers, augment both the quality and quantity of agricultural output, facilitate the transformation of subsistence farming into commercial farming enterprises, and expedite the shift of Indonesia's economic structure from agriculture to industrial. Adopting the appropriate technology for agricultural tools and machinery is crucial, as it directly impacts the effectiveness and efficiency of the production process, leading to enhanced quality and productivity [4,5]

Using agricultural tools and machinery can reduce farming costs and provide benefits for farmers to contribute to achieving food self-sufficiency. Agricultural mechanization has a reasonable prospect if preceded by a mapping of needs, availability, and adequate institutional measures. Consequently, farming costs can be reduced, and efficiency can be improved. The development of agricultural tools and machinery in Indonesia requires good mapping of their needs and availability, as well as institutional efforts to increase their effectiveness [6].

1.2. Research Objective

This review article is intended to provide an overview of the development of agricultural mechanization, challenges and opportunities, and the impact of mechanization on productivity and efficiency, as well as the future prospects of agricultural mechanization.

2. DEVELOPMENT OF AGRICULTURAL MECHANIZATION

2.1. History of agricultural mechanization

This review article is intended to provide an overview of the development of agricultural mechanization, challenges and opportunities, the impact of mechanization on productivity and efficiency, and provide an overview of the future prospects of agricultural mechanization.The historical progress of agricultural mechanization can be attributed to developments in the industrial sector. In particular, this situation occurs in the United States, certain European nations, and Japan. An evident illustration of this phenomenon occurred during World War I and II, when the rural labor force experienced a significant decrease, resulting in a substantial increase in wage levels. However, it is imperative to uphold the production level, making utilizing agricultural tools and technology a fundamental requirement.

The concept of selective agricultural mechanization was first introduced in 1975. It involved the targeted use of Agricultural Machinery Tools based on the region's specific physical and socio-economic characteristics. The Selective Mechanization Model and Direction Atlas for selecting Agricultural Mechanization Technology Levels represent the concept of equivalency in agricultural mechanization technology for rice fields and drylands. The core concept is that there are numerous instances of early adoption of agricultural mechanization before achieving a certain level of stability. This occurs not only in regions that have not undergone intensification due to uniformity in development policies and implementation but also in developed areas that are left to progress without an adequate support system [6].

2.2. The classification of agricultural machinery

The categorization of agricultural machinery technology levels is established by considering four factors: regional physical characteristics, socio-economic conditions, supporting infrastructure, and farming systems.

Regional Physical Characteristics

- Terrain and Soil Type: Smaller, more maneuverable machines like mini-tractors or two-wheel tractors are more suitable in regions with hilly or uneven terrain. Conversely, flat and expansive areas might benefit from larger, more powerful machines like four-wheel tractors and combine harvesters.
- Climate: In areas with heavy rainfall or prone to flooding, machinery that can operate in wet conditions, like track-type tractors, might be more effective. In dry regions, equipment for irrigation, such as drip irrigation systems and water pumps, is essential.
- Soil Conditions: In regions with heavy, clayey soils, powerful tillage equipment such as subsoilers or heavy-duty plows might be necessary. Less intensive machinery like rotary tillers may suffice in lighter soils.

Socio-Economic Conditions

- Income Levels: In low-income regions, more affordable and simple machinery, such as hand-operated tools or two-wheel tractors, are often more suitable. Farmers may invest in more sophisticated and expensive machinery like four-wheel tractors, combine harvesters, and planters as income levels rise.
- Labour Availability: In regions with abundant and cheap labor, less automated machinery might be preferred to maintain employment. In contrast, areas with labor shortages might adopt highly automated machinery, such as robotic harvesters or seeders.
- Access to Finance: In areas where farmers have better access to loans or subsidies, they might afford higher-end machinery with advanced features, such as precision agriculture equipment (GPS-guided tractors, drones for crop monitoring).

Supporting Infrastructure

- Road Access: In regions with well-developed roads, larger machinery like combine harvesters can be easily transported between fields. In areas with poor road access, smaller, more portable machinery might be more practical.
- Electricity and Water Supply: Regions with reliable electricity might use electrically powered equipment, such as electric irrigation pumps or processing units. Areas with unreliable electricity might rely on diesel-powered or manual machinery.
- Repair and Maintenance Facilities: Areas with well-established repair facilities can support the use of more

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complex machinery, as maintenance is more manageable. In regions with limited repair services, simpler, more robust machinery with fewer moving parts is often preferred.

Farming Systems

- Crop Type: Machinery should align with the type of crops grown. For example, rice paddies require specific equipment like rice transplanters and paddy harvesters. Wheat fields might use combine harvesters equipped with grain headers, while orchards might use tree shakers and sprayers.
- Cropping Patterns: In regions practicing mixed or intercropping, flexible machinery that can handle different crops, like adjustable planters and cultivators, is essential. For monoculture systems, specialized machinery, such as single-crop harvesters, may be more efficient.
- Scale of Operations: Small-scale farms might rely on smaller, more versatile machinery like multi-purpose tractors or hand-operated tools. Large-scale operations benefit from industrial-grade machinery, such as high-capacity tractors, large combine harvesters, and bulk handling equipment.

The development approach is a strategy that is selective, holistic, progressive, and participative. The holistic method entails the integrated and synergistic development of agricultural mechanization within a comprehensive system encompassing technology, infrastructure, farming systems, and supporting organizations. A progressive method refers to mechanization's proactive and gradual development to achieve progress. Participatory refers to the involvement of farmers, entrepreneurs, and the government in actively developing mechanization. [7]

2.3. Development of agricultural machinery in Indonesia

The National Medium-Term Development Plan 2020 – 2024 is the 4th stage and continuation of the National Long-Term Development Plan 2005 – 2025. In the fourth National Medium-Term Development Plan (2020-2024), The Indonesian population is anticipated to achieve self-reliance, progress, equity, and prosperity through the expedited advancement of development throughout multiple sectors, including agriculture. This can be achieved by establishing a robust economic framework that leverages competitive advantages across different locations, bolstered by high-quality and competitive human resources. To achieve Indonesia's goal of advanced, independent, and contemporary agriculture, it is necessary to prioritize the development of the agricultural sector. This would not only enhance food security but also improve competitiveness. To attain the objective of augmenting production, it is vital to implement strategic endeavors that are meticulously devised, focused, productive, and can be implemented at national and regional scales. The effectiveness of these strategic initiatives relies on various aspects, with one of the critical factors being the optimization of machine tools, infrastructure, and agricultural facilities. Agricultural infrastructure and facilities play a crucial role in enabling the attainment of national output targets

There are still numerous obstacles to the application of agricultural tools and machinery, including the insufficient availability of production and post-harvest machinery, the optimal placement and utilization of the machinery, the limited ability of farmers to use them, and the low economic ability of the user's farmers. Additionally, the price of agricultural tools and machinery in general is not yet affordable for farmers, particularly for imported products. The development of mechanization technology and improving farmers' welfare necessitates the involvement of the government, academicians, and the relevant private sector at both the central and regional levels.

2.4. The role of the government in the distribution of agricultural machinery

As defined by the Regulation of the Minister of Agriculture Number 25 of 2008, agricultural tools and machinery are used for various agricultural activities such as cultivation, maintenance, harvesting, post-harvest, crop processing, and livestock and animal health. These tools and machinery can be operated either with or without an engine. The utilization of agricultural implements and technology as a means of agriculture is a crucial factor in enhancing the productivity of agricultural commodities. This is derived from the constraints of human labor in manually processing agricultural products. In this scenario, the government offers assistance in the form of agricultural tools and machinery to achieve sustainable self-sufficiency in rice, corn, and soybeans. This assistance is managed through Farmer's Groups/farming tools and machinery service provider business (*UPJA*).

This support is anticipated to enhance the efficiency of agricultural enterprises in producing commodities, particularly rice, corn, and soybeans. The government provides several sorts of agricultural tools and machinery assistance to support the activities of corporate operators in the agriculture sector. The Strategic Plan of the Directorate General of Agricultural Infrastructure 2020-2024 presents data from 2015 to 2020 on the Government Assistance plan, which involves the central allocation and/or regional assistance tasks for Farmers Groups/*UPJA*. The available agricultural equipment includes a two-wheel and four-wheel tractor, a water pump, a cultivator, and a rice transplanter. It is utilized to enhance the density of plants in diverse terrestrial ecosystems. Furthermore, 4-wheel tractors (TR 4) are employed in agricultural production processes to comply with environmental requirements and necessary criteria. The overall number of 2-wheel tractors is 147,117, while there are 11,990 units of 4-wheel tractors. Additionally, there are 113,914 units of water pumps, 15,768 units of cultivators, and 20,335 units of rice transplanted. This support is anticipated to enhance the productivity of agricultural business entities, particularly for rice, corn, and soybean commodities. The government provides assistance with several agricultural tools and machinery to support the activities of corporate operators in the agriculture sector.

The Strategic Plan of the Directorate General of Agricultural Infrastructure 2020-2024 presents information on the period from 2015 to 2020 on the Government support program, which involves the allocation of funds from the central government and/or regional support to Farmers Groups/*UPJA*. Our product range includes two- and four-wheel tractors, water pumps, cultivators, and rice transplanters. It is employed to enhance the density of planting in diverse terrestrial ecosystems. Furthermore, 4-wheel tractors (TR 4) are used in agricultural production operations to adhere to environmental conditions and meet necessary criteria. The overall number of 2-wheel tractors is 147,117, while there are 11,990 units of 4-wheel tractors. Additionally, there are 113,914 units of water pumps, 15,768 units of cultivators, and 20,335 units of rice transplanters.

The rice transplanter machine is an essential agricultural technology that significantly improves the efficiency of rice seed planting. The program to enhance agricultural production is particularly emphasized in rice production centers, where there is still a low level of tools and machinery utilization.

Excavator assistance facilitates the construction, restoration, upkeep, and improvement of infrastructure such as land development, embankments, long-term storage facilities, ditch dams, weirs, barriers, and canals. This assistance aims to promote the development of tidal wetlands, swamps, and other agricultural areas. From 2015 to 2017, a total of 528 units of excavator help were provided based on his requirements.

To attain the strategic objectives set by the Ministry of Agriculture for the 2020-2024 period, it is imperative to enhance significantly the primary production source to reach a high level of agricultural productivity. Hence, it is essential to actively pursue the possibilities and advancements in using agricultural instruments and machines. One potential area for improvement is enhancing the quality of agricultural tools and machinery, which would increase efficiency when utilized in the field. The second aspect pertains to the precision of allocating agricultural tools and machinery to needy farmers by enhancing the distribution system to ensure appropriateness and alignment with the allocation and farmers' requirements. The third objective is to enhance the capacity of *UPJA* institutions and workshops to supervise and manage the utilization and upkeep of agricultural equipment and machinery in the field.

In recent years, the distribution of Agricultural Machinery Tools has faced several issues. This significantly impedes providing agricultural instruments and machinery support, leading to a decline in farmers' production. Furthermore, the progress of agricultural mechanization in Indonesia is currently at an early stage of growth. This is worsened by the sluggish advancement of mechanization technologies at the local level. The protracted development process is attributed to various socio-economic, technical, and institutional impediments. The challenges encountered in the advancement of agricultural mechanization can be observed as follows :

1. Variation in land characteristics, ownership area, and land distribution;
2. The various socio-economic conditions of farmers, especially capital, so that farmers are still unable to have agricultural tools and machinery to support their production;
3. The relatively low level of education, knowledge, skills and culture is one of the factors that affect the development of agricultural technology and the use of agricultural tools and machinery is still lacking;
4. The farming system is still in the subsystem and traditional phase;
5. The existence of *UPJA* institutions and workshops that have not developed optimally due to poor management from technical, economic, and organizational aspects; and
6. There is still weak supervision in terms of the standardization, certification, and testing system of agricultural tools and machinery (agricultural tools and machinery) on the distribution of agricultural tools and machinery assistance from both domestic production and imports, so that the quality is still not guaranteed.

3. CHALLENGES AND OPPORTUNITIES OF AGRICULTURAL MECHANIZATION

Indonesia's agricultural sector plays a pivotal role in the country's economy, supporting the livelihoods of millions of people and contributing significantly to the national GDP. However, the industry faces substantial challenges, including limited land resources, a rapidly growing population, and the increasing impacts of climate change. In this context, agricultural mechanization is a critical strategy to enhance productivity, improve efficiency, and ensure food security. Nevertheless, Indonesia's journey toward widespread mechanization is fraught with significant challenges and promising opportunities that require careful navigation.

3.1. Challenges

The collection of raw materials or business inputs is obtained from the local community's goats purchased without prior processing by the business owner, namely IDR 6,500/sack. The more goats the local community owns, the more goat manure will be produced, and with this, the more raw materials or inputs the business owner will obtain.

One of Indonesia's most significant challenges in advancing agricultural mechanization is the high cost associated with acquiring and maintaining modern agricultural machinery. Smallholder farmers, who comprise most of the farm workforce, often lack the financial resources to invest in expensive machinery such as tractors, combine harvesters, and automated irrigation systems. The prohibitive costs are further compounded by limited access to affordable financing options, making it difficult for farmers to modernize their operations[6].

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Without sufficient capital, these farmers cannot purchase the necessary equipment, which leaves them reliant on traditional farming methods that are less efficient and more labour-intensive.

Moreover, the financial challenges extend beyond the initial purchase of machinery. Maintenance, repairs, and spare parts costs are also significant, particularly in remote and rural areas where such services are scarce. The lack of a well-established market for second-hand machinery further limits options for those who cannot afford new equipment. As a result, the potential benefits of mechanization remain out of reach for many smallholder farmers, perpetuating a cycle of low productivity and limited economic growth.

In addition to financial barriers, inadequate rural infrastructure poses another significant challenge for developing agricultural mechanization in Indonesia. The success of mechanization is heavily dependent on supportive infrastructure, including well-maintained roads, reliable electricity, and efficient water supply systems. However, the infrastructure is underdeveloped or poorly maintained in many rural regions. Poor road conditions make transporting heavy machinery to and from farms difficult, increasing operational costs and reducing the efficiency of mechanized farming practices [8]. Furthermore, limited access to electricity and water restricts the use of certain types of machinery, such as electric-powered irrigation systems, which are essential for modern farming.

The lack of adequate storage facilities is another infrastructural challenge that undermines the effectiveness of mechanization. Farmers cannot preserve their produce for extended periods without proper storage, leading to post-harvest losses and reduced income. This issue is particularly acute for perishable goods, where the absence of cold storage facilities can result in significant wastage. Consequently, losses due to inadequate storage and transportation infrastructure often negate the benefits of increased productivity through mechanization.

Another critical challenge is the shortage of skilled labor and technical expertise needed to operate and maintain agricultural machinery. The successful adoption of mechanization requires a workforce that is knowledgeable about modern farming techniques and capable of handling complex machinery. Unfortunately, there is a significant gap in the availability of such skills in many parts of Indonesia. The agricultural workforce is ageing, and younger generations are increasingly seeking employment in urban areas rather than in agriculture. This shift in labor dynamics has led to a decline in the availability of workers with the technical skills necessary to support mechanization [8]

Furthermore, the lack of accessible and comprehensive training programs exacerbates this challenge. Many farmers and agricultural workers lack the opportunity to receive training in the operation and maintenance of modern machinery. As a result, even when machinery is available, it is often underutilized or improperly maintained, leading to frequent breakdowns and reduced operational efficiency. This diminishes the potential productivity gains from mechanization and increases costs associated with repairs and downtime.

In addition to the economic and technical challenges, environmental concerns present significant obstacles to developing agricultural mechanization in Indonesia. The increased use of heavy machinery in farming can lead to soil degradation, including compaction, erosion, and loss of soil fertility. These issues are particularly problematic in regions with fragile ecosystems or where traditional farming practices have been tailored to local environmental conditions [1]. The shift to mechanized farming also often involves using more chemical inputs, such as fertilizers and pesticides, which can have adverse environmental effects if not managed sustainably.

Addressing these environmental challenges requires a balanced approach integrating sustainable farming practices with mechanization. This includes the adoption of conservation tillage, crop rotation, and precision agriculture techniques that minimize soil disturbance and optimize the use of inputs. However, the dissemination and adoption of such practices are hindered by farmers' lack of awareness and training, further complicating efforts to achieve sustainable mechanization.

3.2. Opportunities

Despite these formidable challenges, numerous opportunities can be leveraged to advance the development of agricultural mechanization in Indonesia. One of the most significant opportunities lies in the strong policy support from the Indonesian government. Recognizing the importance of mechanization for improving farm productivity and achieving food security, the government has implemented various initiatives to support farmers in adopting modern technologies. These include subsidies for purchasing machinery, low-interest loans, and investment in infrastructure development to improve rural connectivity [1].

The government has also established training and extension programs to enhance the technical skills of farmers and operators, ensuring that they are equipped to use and maintain modern machinery effectively. These programs are crucial for building a skilled workforce that can support the expansion of mechanization nationwide. Furthermore, the government's strategic plans for agricultural development, such as the Ministry of Agriculture's Strategic Plan for 2020-2024, emphasize the need for modernization and provide a clear framework for the future growth of mechanization in Indonesia.

Technological advancements and innovations also present significant opportunities for developing agricultural mechanization. The rapid pace of technological development has led to the creation of more affordable and user-friendly machinery better suited to smallholder farmers' needs. Innovations in precision agriculture, such as GPS-guided tractors, drones for crop monitoring, and automated irrigation systems, offer the potential for more efficient and sustainable farming practices [4]. These technologies allow farmers to optimize the use of resources, such as water and fertilizers, reducing waste and minimizing environmental impact.

Moreover, the growing availability of digital tools and platforms is transforming the agricultural landscape in Indonesia. Digitalization offers new ways to enhance the efficiency and effectiveness of farming operations, mainly through improved access to information [9]. Mobile

applications and online platforms provide farmers with real-time data on weather conditions, market prices, and best practices for using agricultural machinery [8]. This increased access to information empowers farmers to make informed decisions, optimize their operations, and improve productivity.

Digital technology also facilitates better supply chain management, enabling farmers to connect directly with buyers and reduce the reliance on intermediaries. This can lead to higher profits for farmers and greater market access for their products. Additionally, the use of digital platforms for training and education allows farmers to continuously improve their skills and knowledge, further supporting the adoption of mechanization.

Another significant opportunity lies in expanding Indonesia's agro-industry and export markets. Mechanization can play a crucial role in enhancing the efficiency and quality of agricultural production, making Indonesian products more competitive in global markets. By integrating mechanization with agro-industrial development, Indonesia can add value to its farming outputs and increase its foreign exchange earnings [6]. Developing agro-industrial clusters, supported by mechanization, can also create synergies between different sectors, leading to more efficient resource use and increased economic opportunities for rural communities.

Furthermore, the focus on developing export markets presents an opportunity for Indonesia to diversify its agricultural economy and reduce its dependence on traditional crops. Mechanization can support the production of high-value commodities, such as palm oil, coffee, and cocoa, with significant export potential. By investing in mechanization and improving the quality and consistency of these products, Indonesia can enhance its position in global markets and achieve excellent economic stability.

4. CURRENT MECHANIZATION POSITION IN INDONESIA

4.1. Modern agriculture

Modern agriculture is distinguished by its high productivity, effective utilization of natural resources and technology, and ability to generate high-quality and value-added output. Modern agriculture is a farming system that involves a wide range of specialized products and increasing use of tradeable inputs. It also emphasizes effective farming management. Agricultural modernization is an ongoing process aimed at enhancing the efficiency and effectiveness of farming operations [10,11]

The strategic significance of agricultural mechanization encompasses several intricate aspects, including the enhancement of productivity, efficiency, and processes, the improvement of quality and added value, and the growth of income.

1. Increased productivity can be achieved by providing additional inputs for seeds, plant seeds or livestock with high yield per unit area. For livestock, it means the weight per unit of livestock, which is caused by the fattening process. Productivity means that the same number of input units also results in higher production.
2. With the increase in the efficiency of the use of agricultural resources, it means an increase in the efficiency of farmers, which in turn also increases economic efficiency.
3. Using agricultural mechanization can improve product quality. Shrinkage due to mechanical damage or due to physical damage can be reduced. The drying or cooling process can extend the storage time and at the same time prevent damage due to natural and artificial factors.
4. Agricultural mechanization contributes to lowering production costs, increasing yields and decreasing yields, so that in the end will increase farmers' income. Basically, the four strategic positions of mechanization demand the prerequisites for completeness and readiness of institutions and human resources as development actors.

Agricultural modernization has been defined by the stages of industrial civilization with high productivity, efficient use of natural resources and technology, and the ability to generate quality and high-value output. In other terms, contemporary agriculture can be defined as a farming system with a wide range of product specializations, increased use of tradeable inputs, and a more effective agricultural management system.

As a result, agricultural mechanization development always begins with farmer needs, followed by stages to achieve sufficient production certainty (subsistence). This then progresses to stages of agricultural business system efficiency and commercialization of farming businesses. Agrarian mechanization has always been linked to developing the agricultural economic system, which has demands.

The transformation of farming from a subsistence farming system to a modern farming system requires time, the preparation of infrastructure, cultural and institutional systems, adequate research support, sufficient counselling, and supporting industries.

Agricultural mechanization innovation in Indonesia runs like an evolutionary process that describes the adoption, adaptation, and application of mechanization from very traditional conditions to modern stages with various levels of technology. These stages are related to the development of infrastructure, the pace of adoption of the farming system, regional economic growth, cultural diffusion, and information flow, which continue to develop from time to time.

Government plays a prominent role in innovation, particularly in disseminating technology. Diverse initiatives, funding opportunities, and alternative mechanisms promote the adoption of agricultural mechanization technology. Nevertheless, the outcomes are not entirely promising. Several variables are either overlooked or not considered in the innovation process. However, the main benefit gained is acquiring knowledge about agricultural mechanization. Specifically, prioritizing human empowerment should take precedence over the modernization process [18].

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4.2. Implementation of modern agriculture

The implementation of agricultural innovation technology contributes to the enhancement of farming enterprises' production, leading to potential improvements in the overall well-being of individuals. This is exemplified by the increased food security observed in farmer households. The majority of rice field farmers have adopted technological advancements such as the intensive *legowo* row system. Similarly, farmers in dryland villages are actively implementing innovative intercropping systems and on-farm agricultural product processing. The utilization of this technology is directly linked to the food security status of farmer households. Specifically, farmers who use technological advancements more extensively demonstrate a higher level of food security [12].

The use of e-agribusiness in the agricultural world is used for agricultural activities that utilize information systems and information technology. An e-agribusiness application can take advantage of open-source web applications so that the creation of an e-agribusiness program does not require a relatively large cost, the web application used is in the form of a content management system, such as Joomla, Drupal, WordPress and others. In this content management system, users can add, edit, manage, and input existing content such as text, graphics, videos, and documents, and can even layout the web created. After creating a website using a content management system, the next thing is to determine the domain name and hosting. In implementing e-agribusiness, it is expected to be able to use existing web applications such as content management systems, so that users who manage e-agribusiness can build their e-agribusiness [[13]

In the agricultural cultivation sector, the drip irrigation system in melon cultivation produces the best quality fruit compared to other systems. Financially, drip irrigation systems are more profitable than other systems (gabion wells, span wells and hoses) in melon cultivation[14].

Another implementation is the use of an unmanned aerial vehicle (UAV) [15]. UAV is a crewless aircraft that is operated remotely. The ability to achieve flight can be accomplished through mechanical or electric means. Mechanical flight relies on a piston engine fuelled similarly to a motor vehicle, whereas electric flight utilizes an electric motor powered by a battery as its energy source. The rotation of the propeller produces the drone's lift. The control system is electric, encompassing both mechanical and electrical components. With the advancement of technology, UAVs can be operated by computer systems, allowing for supervised and restricted flight inside specific areas.

To obtain a map dependent on plants' health, you can utilize the Plant Health map feature found on the drone deploy toolbar upon starting the application. In comparison to the circumstances in the field. Plants exhibiting a yellow leaf colour due to disease or pest infestation will be indicated by a red notice on the plant health map in start-up drone deployment. Conversely, a green notification on the plant health map will indicate plants displaying a green and healthy leaf color. The plant health menu is highly effective for monitoring crops farmed by farmers, especially when considering the extensive land ownership [16].

5. PERSPECTIVE OF FUTURE AGRICULTURAL MECHANIZATION

5.1. Agricultural technology and innovation

The most significant opportunity for added value creation occurs in the agricultural sector in the agroindustry or the middle chain between upstream and downstream. Mastery of value-added creation technology and market access is mastered mainly in the farm product processing business. For this reason, it is necessary to increase high synergy with the industrial and trade sectors to increase agricultural products' added value and competitiveness. The strategy carried out in terms of agricultural development to increase the added value and competitiveness of agricultural products is to increase added value and increase agricultural competitiveness.

Agricultural technology and innovation have proven to be the main factors in increasing the production and productivity of agricultural commodities. Until now, agricultural research and development institutions have produced various technologies and innovations that contribute to the development of the farm sector in Indonesia. In the framework of achieving agricultural development goals through increasing the use of technology and innovation, it is to encourage the creation of innovative agricultural technology in an integrated manner, promote the development of innovative technology, develop location-specific agricultural technology assessments, and strengthen the use of innovative technology

Agricultural tools and machinery are some of the production factors that can affect agricultural pre-harvest. Pre-harvest agricultural tools and machinery help in the agricultural cultivation process. The focus on utilization is how the distributed agricultural tools and machinery can be used appropriately by farmer groups/farmer group combinations/UPJA to support the production of national agricultural strategic commodities. The policy direction of the use of agricultural tools and machinery for region-based agricultural development is carried out with a strategy to increase the use of quality Agricultural tools and machinery equitably [23].

5.2. The utilization of precision agriculture

The utilization of precision agriculture is a cutting-edge technological notion that has emerged in the field of agriculture. Precision agriculture refers to approaches commonly referred to as 'recipe farming,' 'site-specific' farming practices, 'variable level technology,' and other related words. The fundamental principle of precision agriculture is to quantify and control variations, such as crop yields, soil characteristics, pest infestations, and weed growth, within a given land area to enhance the effectiveness of agricultural management in planting systems. In this way, productivity, product quality, and economic returns can be more optimal.

The use of technology can also minimize environmental impacts and agricultural risks. Due to the differences in each land, future farmers use satellite images, drones, and other geographic tools. The step taken is to observe the types of plants suitable for planting on agricultural land. Then, a sensor system will be built on the

farmland to measure the humidity and temperature of the soil and air around the land. Farmers need accurate information about soil conditions, watering, fertilizing, or pesticides to be used effectively only where required.

In Indonesia, the adoption of precision agriculture has been directed by numerous start-ups and companies that utilize advanced big data analytics technology to develop agricultural management systems. These systems leverage weather analysis, soil sensor data, and satellite and drone imaging to enhance agricultural productivity. Precision agriculture employs sensor systems, drones, and remote sensing to collect data for smart farming systems, improving the accuracy of farming business management. The system can guide agricultural activities of aided farmers or farmer groups and communities (including bank-supported communities, microfinance, and independent food producers) to enhance the effectiveness and efficiency of farming operations.

The created tracking system innovation can take the shape of an integrated information system for the supply chain of agricultural commodities. The system can be developed to connect farmers, distributors, markets, and end customers by utilizing mobile applications to input accurate data on the current level of supply and demand and issues encountered in the field at each stage of the supply path [17].

The Internet of Things (IoT) will be useless if it cannot be applied at the grassroots or end-user level. The process of transitioning from traditional to modern agricultural patterns to the implementation of smart digital farming will not necessarily run on its own. The role of mentoring and field learning is crucial to assist farmers in implementing technology in the agricultural process from upstream to downstream [17].

Sustainable agriculture is a form of future agriculture because it can play a dual role: economic, food, energy, and environmental services. Sustainable agricultural development is necessary considering the challenges of increasingly severe environmental conditions and the demands of meeting equally strong needs. Current ecological conditions show land degradation, scarcity of clean water, biodiversity loss, decline in agricultural genetic biodiversity, and climate change. Meanwhile, the demand for meeting food, water, and energy needs has increased along with the increase in population.

Various methods that support agriculture have been developed to accelerate the implementation of smart farming in Indonesia. Image processing is one of the technologies that can be applied to develop agriculture in Indonesia. Image processing has developed in many sectors, such as healthcare, factories, and working processes. Image processing technology in agricultural commodities detects and classifies ripe and unripe tomatoes. The accuracy value obtained using this method is 95%, while the precision value obtained is 96%, and the recall value obtained is 94.11% [18]

The adoption of digital technology also contributes to the production stage. The application of digital technology at the production stage is an example of using drones, agricultural robots, remote sensors, and agricultural management software. The existence of sensors in soil and water is beneficial for farmers to collect data, which further provides information to farmers [19]. So, farmers know when is the right time to plant water-consuming crops such as rice or drought-resistant crops such as beans and tubers. There is also a technology called dino weeding robot that helps weed vegetable farmers with a very high level of precision, and farmers can save time.

At the sales and distribution stages, e-commerce-based digital technology can offer farmers more attractive and profitable prices. This is because the role of e-commerce is to sell products from farmers directly to consumers. Even blockchain technology can be applied to detect poor-quality agricultural products so that they can be immediately followed up [20]

Examples of startups in Indonesia that have digital technology that can be used to help farmers include villages with DataHub Farming, a data platform that has a product called LISA, an SMS-based information network that provides information and news for farmers who subscribe; Habibi Garden has IoT-precision farming technology that uses sensors to detect moisture, temperature and nutrient levels in the soil; TaniHub has an e-commerce platform that sells farmers' products directly to consumers [21]

Given the existence of parties capable of offering digital technology to farmers, the subsequent objective is to enable farmers to implement this technology successfully. To achieve digital agriculture, numerous fundamental requirements must be fulfilled. These criteria encompass the presence of a robust internet infrastructure and the government's unwavering dedication and comprehensive backing regarding information, technology, and human resources [12].

6. CONCLUSION

This review article is intended to provide an overview of the development of agricultural mechanization, challenges and opportunities, the impact of mechanization on productivity and efficiency, and the prospects of agricultural mechanization. The development of agricultural mechanization in Indonesia is inseparable from the situation and conditions of the strategic environment of the local community. Therefore, a system approach to the sociocultural transformation of society is needed by considering the diversity in each regional culture. Given this, the development of agricultural mechanization in Indonesia adheres to the principle of selective agricultural mechanization, namely introducing farming tools and machinery to the conditions of the local area. It is essential to dare to dream and imagine things that we can achieve at some point, just like the dreams and ideals of our predecessors, which, in the end, we can gradually witness and feel together today.

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