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Enhancing Agricultural Productivity in the Philippines: A Comprehensive Review of Mechanization Status and Sustainable Strategies

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ABSTRACT

This review examines the current status of agricultural mechanization in the Philippines and its impact on productivity while identifying sustainable strategies to address existing challenges. Despite the importance of agriculture in the national economy, mechanization levels remain low, constrained by financial barriers, inadequate infrastructure, and limited technical knowledge among farmers. The review highlights the necessity of promoting inclusive access to mechanization through cooperative models and government subsidies, alongside enhancing training and capacity-building initiatives. Additionally, it emphasizes the role of innovative technologies, such as smart agriculture and eco-friendly machinery, in boosting efficiency. Finally, a robust policy framework is essential for fostering research and development in agricultural technologies. The Philippines can significantly enhance agricultural productivity by implementing these strategies, contributing to food security and economic resilience.

Keywords: Agricultural mechanization, Agricultural productivity, Food security, Innovative technology

INTRODUCTION

Agriculture plays an important role in the Philippine economy, contributing to both employment and food security. The number of employed people in agriculture reached up to 10.66 million by 2021 and in terms of share, agriculture accounted for 24.2 percent of the country's employment (PSA, 2022). This only means that the number of gainfully employed in agriculture reflects the sector's capacity to acquire available labor and its overall contribution to the Philippine economy.

Furthermore, the Philippines depends on farming and fishing. The archipelago's diverse climate, fertile soils, and varied topography make it suitable for cultivating various crops and supporting a substantial fisheries industry. The key agricultural products include rice, coconut, sugarcane, bananas, corn, and pineapple, with rice serving as the staple food for most Filipinos. Additionally, livestock and poultry production, as well as aquaculture, are vital sub-sectors of agriculture, contributing significantly to food supply and rural income (FAO, 2014). The total palay volume production was 20.06 million metric tons which is the highest harvest in the country and corn is 17,005.45 metric tons in 2023 (Panay News Agency, 2024).

However, the Philippines' agriculture sector faces significant challenges such as low productivity, obsolete farming practices, and vulnerability to climate change. In response, agricultural mechanization has emerged as a critical strategy for enhancing productivity, improving efficiency, and achieving sustainable development in the sector (Amongo, 2020). Agricultural mechanization refers to the use of all means of machinery and equipment, from

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simple and basic hand tools to more sophisticated and motorized machinery, in agricultural operations (FAO UN, 2022). It also includes production, distribution, and utilization of a variety of tools, machinery, and equipment for the development of agricultural land, planting, harvesting, and primary processing (Emami, 2018).

Despite the clear benefits, the adoption of mechanization in the Philippines has been slow and uneven, particularly in rural areas. Factors such as high costs, limited access to credit, and inadequate infrastructure have hindered widespread implementation (Tomar & Tomar, 2023). Additionally, the country's fragmented land ownership structure and the prevalence of smallholder farms present significant barriers to large-scale mechanization. Smallholder farming dominates the landscape, with over 80% of the country's farms being less than two hectares in size (Lowder et al., 2016). Many farmers still rely on traditional farming practices, such as manual labor and animal-drawn plows, making their productivity vulnerable to inefficiencies. Low levels of productivity, persistent poverty among rural households, and vulnerability to climate change and market fluctuations are among the challenges facing the sector. Additionally, issues such as land fragmentation, poor rural infrastructure, and limited access to credit and technology have stymied the growth of agriculture (Tomar & Tomar, 2023).

For a country like the Philippines, which has historically lagged in mechanization compared to its neighbors in Southeast Asia, embracing modern farming technology is key to overcoming productivity bottlenecks and ensuring food security. As the government continues to promote agricultural modernization through various policies and programs, including the Rice Competitiveness Enhancement Fund (RCEF), there is a growing need to assess the status of mechanization and identify sustainable strategies for its expansion (DA-RCEF, 2024).

This review aims to assess the current status, challenges, and opportunities and provide strategic recommendations to achieve sustainable agricultural mechanization in the Philippines.

It specifically aims to:

1. Discuss the existing agricultural mechanization practices and their impact on productivity and sustainability in the Philippines.
2. Identify the key challenges and barriers hindering the widespread adoption of mechanization in different agricultural sectors.
3. Explore emerging trends and opportunities in agricultural technologies that can enhance mechanization efficiency and farmer participation.
4. Provide future strategic approach recommendations that support long-term mechanization goals and improve the sustainability of the agricultural sector.

METHODOLOGY

The methodology began by searching for studies on the current mechanization level, its benefits, and sustainable strategies for improvement. A comprehensive literature review was conducted by analyzing studies from the Philippines and other countries to identify mechanization trends, challenges, and policy impacts. Quantitative data, including national statistics on mechanization, crop yields, and regional disparities were collected. International case studies were compared to the Philippine context to identify best practices that could be adapted locally. Recommendations for sustainable strategies, including policy reforms, technological innovations, and private-sector partnerships were developed based on the analysis. The final report provided actionable recommendations to enhance agricultural mechanization and productivity in the Philippines.

CURRENT STATUS OF AGRICULTURAL MECHANIZATION IN THE PHILIPPINES

The technology for agricultural mechanization has been transferred relatively slowly. In 1990, the Philippines had a mechanization level of about 0.52 horsepower per hectare (hp/ha) based on available mechanical power in farms (RNAM, 1994). This level of agricultural mechanization is comparatively low, and it was primarily due to this low level of mechanization that rice production could not reach its maximum yield (Committee Affairs Department, 2009).

Nevertheless,1.69 horsepower per hectare was the level of agricultural mechanization in 1994 (Rodulfo & Amongo, 1994). According to the survey conducted by the Philippine Center for Postharvest Development and Mechanization (PhilMech), farms in the Philippines are now mechanized to the tune of 2.679 horsepower per hectare (hp/ha), which is a significant improvement from the 2.31 hp/ha estimated in 2013 (PhilMech, 2013). This increase in the country's farm mechanization level can be attributed to the impact of the Rice Competitiveness Enhancement Fund (RCEF)-Mechanization Program which is now in its fifth year of implementation (DA-PhilMech 2023). The government earmarks P5 billion or half of the P10 billion collected annually from rice tariffs for PhilMech to implement the mechanization part of RCEF from 2019 to 2024 (Inquirer.net, 2023).

Based on PhilMech's assessment, the highest mechanization level was logged in Region 2 with 3.5079 hp/ha, while the lowest was in the Bangsamoro Autonomous Region in Muslim Mindanao (BARRM) with 0.9031 hp/ha. The other regions and their respective farm mechanization level are Cordillera Administrative Region with 2.3523; Region 1 with 3.0936; Region 3 with 2.6177; Region 4A (Calabarzon) with 3.3569; Region 4B (Mimaropa) with 2.2233; Region 5 with 2.9844; Region 6 with 2.7616; Region 7 with 3.019; Region 8 with 2.4131; Region 9 with 1.5908; Region 10 with 2.2967; Region 11 with 2.5912; Region 12 with 1.7217; and Region 13 with 1.6532 (DA-PhilMech 2023).

Under the RCEF-Mechanization Program, PhilMech distributed a total of 22,844 units of various farm machines to 10,633 farmers' cooperatives and associations (FCAs) and local government units (LGUs) covering the funding years 2019 to 2022. The biggest portion of farm machines distributed were for land preparation at 12,644 units comprising four-wheel tractors, two-wheel tractors/power tillers, floating tillers, and farm implements/attachments. Meanwhile, for crop establishment, 3,387 units of machines were distributed composed of precision seeders, walk-behind transplanters, and riding-type transplanters. For harvesting and threshing, a total of 6,979 units of machines were distributed made up of reapers, combine harvesters, and threshers. Finally, 1,338 units of facilities were distributed for drying and milling (DA-PhilMech 2023).

However, the country's rice farms have seen little improvement in the use of machinery and equipment even if the government poured in billions of pesos for farm mechanization in previous years. With just a 16-percent improvement over nine years, the Federation of Free Farmers (FFF) flagged several factors behind the slow uptick in farm mechanization efforts. It is possible that the machines are not being properly maintained and become unutilized after a few years and farmers are hesitant to buy machines unless given to them for free because the low prices of palay brought about by excessive imports discourage investments (Inquirer.net, 2023).

On the other hand, Table 1 shows the level of the Philippines' agricultural mechanization in major crops such as rice, corn, vegetables, legumes, root crops, coconut, fruits, fiber crops, sugarcane, and pineapple (Sumistrado, 2013). The level of mechanization in different operations in most crops/products is low aside from sugarcane. Though harvesting is done manually, sugarcane has a relatively higher level of mechanization in different operations ranging from intermediate to high for land preparation, low to

intermediate for transplanting, and low to high for cultivation. In land preparation, only rice, corn, and sugarcane have intermediate to high levels. The availability of imported, locally fabricated, and second-hand (imported) hand tractors in plowing, rototilling, and harrowing operations has increased the level of mechanization in land preparation operations.

Table 1. Level of Mechanization of Crops in the Philippines

Operation	Rice/Corn	Vegetables, legumes, and root crops	Coconut/Fruits/ Fiber Crops	Sugarcane, pineapple
Land preparation	Intermediate to high	Low		Intermediate to high
Planting/transplanting	Low	Low	Low	Low to intermediate
Crop care/cultivation	Low	Low	Low	Low to high
Harvesting	Low	Low	Low	Low
Threshing/shelling	Intermediate to high	Low (legumes)		
Cleaning		Low		
Drying	Low	Low (legumes)	Low	
Milling/village-level processing	High	Low	Low	

Source: Sumistrado (2013)

In crop establishment, manual seeding is mostly done through the broadcasting of seeds and manual transplanting through hired labor. Only a few used sowers, drum seeders, and mechanical transplanters due to the expensive price of acquiring the machinery. The level of mechanization in harvesting is high due to local and imported harvesting machinery such as threshers and combine harvesters. Rice reapers were only used by farmer-owners and utilized only on their farm. Drying of palay is mostly done by sun drying and few used mechanical dryers because most farmers sell their harvest to traders after harvesting. Drying at the farmer's level is usually involves sun drying using roads and multipurpose pavements such as basketball courts. Milling or village-level processing in rice and corn has also a high level of agricultural mechanization. Small-scale rice millers used rubber roll rice milling machines while big rice millers used modern rice mills (Amongo et al., 2011). Other operations in most of the crops are still manually done.

As shown in Table 2, although the level of agricultural mechanization in the Philippines has improved recently, this is relatively lower than other neighboring countries such as Japan with 18.9 hp/ha, South Korea with 9.4 hp/ha, and China (8.4hp/ha) in 2011. Among the members of Southeast Asia which the Philippines has a Free Trade Agreement (AFTA), it also shows that the Philippines has a low level of mechanization through the number of tractors available. There are still more things to do when it comes to the agricultural mechanization of the country. In today’s scenario wherein there are many new technologies available for agriculture, the Philippine agriculture sector, in general, is still characterized by low production levels, high post-harvest losses, and the inability to transform their raw form into high-quality products.

Table 2. Mechanization Level of Different Countries

Country	Mechanization Level (hp/ha)		
	1968	1990	Recent year
Japan	3	7	18.87 (2011)
Republic of Korea	0.435	4.11	9.38 (2011)
People's Republic of China	Not available	3.88	8.42 (2011)
Pakistan	0.41	1.02	Not available
India	0.302	1	2.22 (2011)
Thailand	0.348	0.79	4.20 (2009)
Vietnam	Not available	Not available	Not available
Iran	0.239	0.7	Not available
Sri Lanka	0.378	0.58	Not available
Philippines	0.198	0.52	2.679 (2017) all crops
Indonesia	0.173	0.41	Not available
Bangladesh	Not applicable	0.4	1.46 (2008)
Nepal	0.733	0.3	Not available

Source: Baustista et al. (2017)

BENEFITS OF AGRICULTURAL MECHANIZATION

Agricultural mechanization significantly enhances farming practices by improving productivity, efficiency, and overall sustainability. This section highlights its diverse benefits, including positive impacts on labor dynamics, economic viability, land management, environmental sustainability, social equity, access to finance, and market infrastructure.

Productivity and Efficiency. Agricultural mechanization substantially enhances productivity and efficiency, providing numerous benefits to farmers and agricultural systems. The adoption of agricultural machines and technologies enables farmers to increase production with less input and time, contributing to food security and meeting the rising demand of a growing population. Verma (2006) noted that mechanization improves agricultural production through timely and efficient operations, with tractor farms achieving up to 152% higher gross income per hectare compared to traditional farming. In Benin (2015), mechanization was found to enhance farming scale, improving efficiency and leading to higher agricultural output. Camarena (2003) reported that mechanization accelerates farming operations, reducing the time for planting, cultivating, and harvesting. Additionally, machinery utilization lowers costs, making it more economically viable for farmers to adopt environmentally friendly production techniques. Studies by Caunedo and Kala (2021) and Rajkhowa and Kubik (2021) highlighted increased mechanization hours and reduced raw material expenditures, contributing to overall cost savings and agricultural labor productivity growth. Gollin et al. (2014) found that production efficiency differences among eighty countries were largely due to mechanization. The promotion of modern agricultural machinery is expected to enhance farm productivity and efficiency, significantly lowering labor costs for labor-intensive crops like rice. Mechanization has made agricultural production more efficient and sustainable, reducing losses during production and post-harvest processes (Agriculture Magazine, 2019). In the Philippines, Rodulfo, Jr., et al. (2021) emphasized that mechanization facilitates faster completion of farm operations, ensuring optimal timing for land preparation, planting, and harvesting. By employing machinery, farmers minimize crop losses and streamline processes, ultimately increasing productivity. Mechanized farming allows farmers to cultivate more land or grow multiple crops per season, maximizing farmland use, reducing costs, and enhancing market competitiveness. The time saved from mechanized operations can be allocated to other productive activities, further improving overall farm productivity.

Labor and Workforce. Agricultural mechanization positively affected labor and the workforce by addressing labor shortages, improving working conditions, and increasing the overall efficiency of farm operations. It reduces the physical demands of farming, enables a more productive use of available labor, and contributes to rural employment opportunities. Families that reduced their labor input in farming due to mechanization were able to reallocate their efforts to non-agricultural income-generating activities. As a result, non-agricultural income increased significantly, with a point estimate of 40% reported in the study by Caunedo and Kala (2021). According to Benin (2015), mechanization alleviated the physical demands on farmers, making farming less labor-intensive and more manageable. Verma (2006) stated that while it displaces some animal power, mechanization creates new jobs in machinery operation, maintenance, and non-farm sectors, helping to alleviate rural unemployment. Mechanization enhanced productivity and generated non-farm employment in agro-industrial sectors, offsetting direct farm employment losses. Yamauchi (2016) claimed in his study that mechanization allowed farmers to substitute labor with machines, effectively reducing dependence on manual labor. This is particularly crucial as labor costs increase, making it more financially viable to use machinery. Hamilton's (2021) study showed that mechanization can help alleviate chronic labor shortages in agriculture, particularly in sectors reliant on manual labor where workers may be difficult to recruit or retain. Mechanized harvesting aids can complement manual labor, allowing workers to achieve higher productivity levels. In scenarios where mechanization complements rather than substitutes labor, higher productivity can lead to increased wages for workers. This dynamic encourages investment in productivity-enhancing technologies. Meng Meng et al. (2024) indicated that mechanization affects worker mobility primarily by displacing agricultural labor inputs rather than expanding land scale. Rajkhowa and Kubik (2021) also stated that the introduction of machines decreases the reliance on manual labor. Different types of machines, such as tractors and power tools, can perform tasks quicker than human labor alone. Mechanized processes can enhance the quality of agricultural work, such as more consistent planting and harvesting, which can lead to better crop yields. Rodulfo, Jr., et al. (2021) claimed that in the Philippines, due to mechanization and with reduced labor needs for certain tasks, farmers can reallocate labor to other areas or use it for higher-value tasks, improving overall labor utilization. Mechanization minimizes the physical labor required for farming tasks, which is particularly beneficial given the aging agricultural workforce. It also supports the agricultural sector in adapting to shifts in labor, as fewer workers are needed for traditional methods, allowing for greater efficiency with a decreasing labor force.

Economic and Cost Factors. Agricultural mechanization offers significant economic and cost-related benefits to both individual farmers and the agricultural sector. These advantages stem from improved productivity, reduced labor costs, more efficient use of inputs, and long-term savings from investment in machinery. Mechanization enhances the profitability of farms and can play a vital role in the development of rural economies. Hamilton (2020) stated that mechanization can provide a long-term solution for agricultural labor issues, encouraging investment in technologies that continuously enhance output rather than relying solely on human labor. Yamauchi (2016) emphasized that mechanization allows farms to adapt to changing labor market conditions, reducing dependence on foreign guest workers and increasing the competitiveness of agricultural production.

Farm Size and Land Management. Agricultural mechanization brought benefits to farm size and land management by enabling more efficient use of land, supporting larger-scale farming, and improving land productivity. Mechanization allows farmers to manage larger plots of land with fewer resources and enhances the precision of land preparation, planting, irrigation, and harvesting. According to the study by Rajkhowa and Kubik (2021), mechanization offers diverse equipment options. The diversity of agricultural machines,

including water-lifting equipment, tractors, and threshers, allows farmers to address specific tasks effectively, contributing to more thorough farm management. Also, mechanization can facilitate the cultivation of larger areas of land, thereby potentially increasing agricultural output. Yamauchi (2016) also added that mechanization facilitates the renting of land, enabling larger, relatively well-endowed farmers to expand their operational land size. This is achieved through renting land and utilizing hired machines, which can contribute to economies of scale. According also to Bautista et al. (2017), larger farm sizes can benefit from mechanization, reducing per-unit production costs and improving overall profitability. Mechanized farming can facilitate better land management practices, such as precise planting, irrigation, and harvesting, leading to optimized resource use and reduced waste.

Environmental and Sustainability Impacts. Agricultural mechanization contributed to environmental sustainability when integrated with modern practices like precision agriculture and conservation tillage. Mechanization enhances the efficient use of resources such as water, fertilizers, and energy, while also reducing environmental degradation and greenhouse gas emissions. Daum (2020) reported that mechanization improves soil fertility due to better land preparation and cultivation of previously uncultivated land yet, over time too much plowing leads to soil erosion and compaction that leads to long-term decline. It is stated by FAO (2016) that designating appropriate machines and tools for the agricultural production chain is vital to increasing outputs in a sustainable way. Carefully chosen machinery can allow crops to be grown and harvested with minimum-to-no soil disturbance, ensure that the soil surface remains protected by an organic cover, manage crop rotations to enhance soil health and conserve crop nutrients. According also to Daum (2023), mechanization allows for more efficient use of land and resources, potentially leading to better environmental management. Wanglin Ma and Dil Bahadur Rahut (2024) emphasize that mechanization can lead to better management of inputs like pesticides and fertilizers, optimizing their use and reducing waste. It promotes sustainable practices, such as zero/minimum tillage, which conserves soil health and reduces pesticide use, leading to lower environmental degradation.

Social and Community Impacts. Agricultural mechanization has several social and community benefits that can significantly enhance rural life and overall community dynamics. Daum (2020) stated that mechanization leads to higher incomes, allowing households to buy more diverse food and cover education expenses. It also creates rural jobs, and additional income provides financial independence and the ability to manage risks associated with agricultural production. Also, access to mechanization can significantly empower female farmers, enhancing their social status. It can also alleviate the workload for women, particularly in weeding and harvesting, and allows women to engage more in agricultural production and decision-making, potentially shifting traditional gender roles in farming communities. Daum (2023) also stated that it alleviates the heavy toil of farming, particularly benefiting women and children by freeing up time for other activities. When implemented inclusively, mechanization can enhance economic opportunities and reduce disparities among different farming groups, promoting social equity. Wanglin Ma and Dil Bahadur Rahut (2024) also stated that it can enhance farm profitability and economic diversification, improving livelihoods and reducing poverty in farming communities.

Access to Finance and Credit. Agricultural mechanization enhances access to finance and credit for farmers, significantly transforming their economic landscape. Traditionally, many smallholder farmers face challenges in securing financial resources due to a lack of collateral, inadequate financial literacy, and the perceived risks associated with agricultural investments. However, mechanization introduces a range of opportunities that can mitigate these barriers. Government policies and programs that subsidize farm equipment purchases can make mechanization more accessible, promoting ownership and expansion of machinery

use among farmers (Rajkhowa & Kubik, 2021). Jiang et al. (2024) stated that farmers' cooperatives possess information advantages, as financial institutions gain access to smallholder farmers' information through the organized value chains of farmers' cooperatives, leading to a direct reduction in transaction costs and an improvement in access to credit. They can promote smallholder farmers' agricultural investments, increase household income for smallholder farmers, enhance the liquidity of farmland, and further improve access to credit for smallholder farmers. IFC (2014) stated that access to financial services is critical to provide funds for farm investments in productivity, improve post-harvest practices, smooth household cash flow, enable better access to markets, and promote better management of risks. Access to finance also plays an important role in climate adaptation and increases the resilience of agriculture to climate change, thus contributing to longer-term food security. Access to a comprehensive range of financial services is a significant challenge for smallholders, who constitute most farmers in developing countries.

Market Access and Infrastructure. Agricultural mechanization significantly enhanced market access and infrastructure, which are critical components for the success and sustainability of farming operations. In developing regions, farmers often face considerable challenges in bringing their produce to market due to inadequate transportation networks, poor storage facilities, and limited access to processing technologies. Mechanization plays a transformative role in addressing these challenges by increasing the efficiency and effectiveness of agricultural practices, ultimately leading to improved market connectivity. Caunedo and Kala (2021) stated that mechanization facilitated access to rental markets for smallholder farmers, helping to overcome barriers related to indivisibilities in purchasing agricultural equipment (Sims & Kienzle, 2016). It is stated that making mechanization available to smallholder farmers includes subsidies, strong extension services, infrastructure development, and a solid manufacturing sector that prioritizes the smallholder sector. Infrastructure development, especially for transport but also of utilities, is key to encouraging agricultural development.

CHALLENGES FACING AGRICULTURAL MECHANIZATION

Agricultural mechanization has the potential to significantly enhance productivity and efficiency in the Philippines, yet it faces various challenges that hinder its widespread adoption. These challenges encompass economic and technological barriers, as well as socio-cultural factors that impact labor dynamics and the livelihoods of rural communities.

Economic and technological barriers. Agricultural mechanization in the Philippines faces several technical barriers. Land preparation and shelling are moderate to highly mechanized, but other activities like planting and crop care remain predominantly manual (Dela Cruz & Malanon, 2017). The challenges of agricultural mechanization are brought about by technical, socio-economic, environmental, and infrastructural factors. The technical aspect includes high acquisition costs, inappropriate technology, and low research and extension capability for appropriate farm machinery. The socio-economic aspect involves low income or lack of capital, small landholdings, unfavorable market prices for farmers, and seasonal labor shortages. Furthermore, the challenges of agricultural mechanization include a lack of infrastructure, diversity in agroecosystems, a weak agricultural manufacturing industry, and environmental degradation (Elepaño et al., 2009). Key challenges include inefficient subsidy payment methods for machinery purchases and a lack of updated information for formulating relevant programs (Dela Cruz & Malanon, 2017; Bagheri & Bordbar, 2014).

Other issues faced include the unavailability of machinery in the local area, outstanding credit in banks, and the unavailability of spare parts. Both the government and private sectors needs to address the appropriate combination of hand tools, animal draft, and mechanical

power technologies for specific conditions, as well as the introduction of the right level of technology to achieve higher productivity (Dinio & Nape, 2022). The challenges faced included the high cost of fuel and oil for agricultural machinery, expensive maintenance, difficulty in finding spare parts locally, high equipment costs, outstanding bank loans, and small farm size (Garcines, 2019).

The promotion of farm mechanization in the Philippines has been limited by the small and inaccessible rice fields, particularly during the rainy season, as well as irregularly shaped farm areas. Mechanizing these lands can be inefficient due to the need for excessive maneuvering during operations such as land preparation and harvesting. The use of machinery and other large-scale agricultural practices is hindered (Bautista, 2017). Machinery literacy, such as awareness, training, and seasonal factors, is crucial to maximizing the program's impact (Cayetano et al., 2023). The technology transfer strategies are crucial, requiring careful assessment of mechanization needs and appropriate machinery selection (Paras & Amongo, 2006). Addressing these barriers requires a multifaceted approach, including improvements in programming, technical aspects, infrastructure, management, economics, research, and extension services (Bagheri & Bordbar, 2014). Thus, the investment of technology and necessary support services is an important requisite for successful agricultural transformation. Inadequacy of such investment has been a long constraint to agricultural growth (Brown et al., 2018). Overcoming these challenges is essential for enhancing agricultural productivity and supporting agro-industrial development in the Philippines.

Socio-cultural factors. Agricultural mechanization in the Philippines has been a subject of concern due to its impact on employment and income distribution. While mechanization can enhance efficiency, it also poses challenges to farm laborers' livelihoods (Dilla et al., 2024). Rahman, Miah and Hossain (2011) conclude that mechanization has adverse effects on family labor and more research needs to be conducted to develop appropriate technology to increase production without substituting labor. The non-adaptation of agricultural machinery is due to factors of education, farm size, and land ownership.

Studies have shown that the introduction of modern machinery has contributed to unemployment and financial hardship among farm workers, as well as eroding traditional communal practices (Dilla et al., 2024). According to Secretaria (2019), farmers resist new agricultural technologies due to poverty and lack of resources. The extensive use of mechanization, specifically for land preparation, planting, harvesting, threshing, and shelling, decreased the demand for manual labor in terms of man-day per hectare requirement (Rodulfo et al., 2021). According to Calibuso et al. (2021), agricultural land workers in the community were found to have low levels of education. The wages they earned as farm workers after the introduction of farm machinery were insufficient to meet their needs for food, education, housing, and electricity. Additionally, due to their limited education, it was challenging for them to find alternative employment that could adequately support their needs. Almost half of the respondents' perception of agricultural mechanization (44%) will make farming easier and 12% said that agricultural mechanization displaces labor. Some believe that the advantage of machines (4%) in large farms only.

Employing coping strategies like minimizing food expenses and seasonal migration to address the negative effects of agricultural mechanization on their employment and livelihoods (Declaro-Ruedas & Bais, 2020). Advances in farm mechanization have been made where a strong demand for labor in other industries has withdrawn workers from the land and forced wage rates up. Increasing the use of farm machines requires less and less human power, while it is expected that mechanized farming leads to more productivity, the reverse is true for displaced farm workers (Kempis, 2019). Farmers' awareness of farm mechanization and land reformation appears to be very low, and they also have financial

problems when they consider adopting farm mechanization and land reformation. Therefore, it is essential to raise farmers' awareness and provide financial subsidies to farmers willing to adopt mechanization and land reformation (Bautista, 2017). These findings highlight the complex challenges in promoting agricultural mechanization in the Philippines, balancing efficiency gains with socio-economic impacts on rural communities.

STRATEGIC APPROACHES FOR LONG-TERM SUSTAINABILITY

Enhancing agricultural productivity in the Philippines necessitates the integration of mechanization with sustainable practices to effectively tackle the food security challenges posed by a growing population, projected to reach 153 million by 2050 (Payumo et al., 2013). Modern technologies and sustainable methods can significantly boost agricultural output while fostering environmental and economic resilience. Mechanization plays a pivotal role in this transformation by improving efficiency, reducing labor costs, and increasing yields. This is exemplified by the Rice Competitiveness Enhancement Fund (RCEF), which aims to advance mechanization among Farmers' Cooperatives and Associations (FCAs) for improved rice production (Cayetano et al., 2023).

However, the effective implementation of mechanization faces challenges, including limited access to funding, inadequate training on new technologies, and difficulties with equipment maintenance. Addressing these issues requires supportive policies and infrastructure development that enable widespread adoption within the agricultural sector. Ensuring farmers have the necessary resources and skills to operate and maintain new machinery is crucial for realizing the benefits of mechanization. Policymakers should combine mechanization with investments in research, financial incentives for adoption of technology, and educational programs aimed at enhancing farmers' skills. Future research should investigate the socioeconomic impacts of mechanization on farmer income and community development to ensure tailored solutions that meet the unique needs of Philippine agriculture while contributing to long-term productivity and sustainability.

Government policies and initiatives play a critical role in supporting mechanization through subsidies and financial assistance, which are essential for market stability, food security, and rural development. Between 2010 and 2015, agricultural subsidies in the Philippines averaged PHP3.36 billion annually (Inocencio, 2024), funding irrigation systems and crop production initiatives through government-owned and controlled corporations (GOCCs). Additionally, specialized programs targeting sectors like dairy farming, papaya, and seafood received significant financial backing during this period. In response to rising production costs, the government has introduced a $10 million fuel subsidy for farmers and fishers (USDA, 2022), while the 2024 national budget allocates P197.84 billion to agriculture (DBM, 2024), covering key areas such as rice production, livestock, and high-value crops. Programs like the AgriNegosyo Loan Program have also provided financial assistance, distributing P80 million thus far (ACPC, 2024). The RCEF further supports loans, seed development, and equipment procurement to enhance rice production and farmer incomes. While these subsidies have historically contributed to agricultural growth, they can distort market competition. Thus, policies must balance necessary support with maintaining a competitive environment, making regular reforms and evaluations critical to aligning subsidies with sustainable agricultural development goals.

To complement financial initiatives, training and education programs are vital for maximizing the benefits of mechanization. The Agricultural and Fisheries Mechanization (AFMech) Law of 2013 establishes a legal framework that promotes the adoption of modern, cost-effective, and environmentally friendly agricultural machinery (Asayas, 2024). Various educational programs have been initiated to train individuals in the use, operation, and maintenance of such machinery, ensuring a skilled workforce within the agricultural sector.

The government implements intensive training tailored for Agricultural Extension Workers (AEWs) and farmers, covering a broad spectrum of agricultural production, from land preparation to machinery operation, ultimately enhancing AEWs' ability to effectively support farmers (ATI, 2024). Collaboration with institutions like the Department of Agriculture (DA) and the Philippine Center for Postharvest Development and Mechanization (PHilMech) is crucial for delivering comprehensive training and advisory services that reflect the latest advancements in agricultural techniques and mechanization. Initiatives such as the "Training of Trainers" program are pivotal in creating a new generation of trainers who will disseminate mechanization knowledge within the farming community. This approach aims to achieve a long-term impact on agricultural productivity as trained AEWs equip farmers with the necessary skills and insights to adopt modern mechanization practices. Continuous learning opportunities, including seminars and distance education, further support ongoing farmer development (PhilMech, 2024), contributing significantly to enhancing agricultural productivity and food security in the Philippines.

In addition to government efforts, private sector involvement is crucial for advancing agricultural mechanization through partnerships with machinery manufacturers. Recognizing this need, the government has implemented various policies to promote public-private partnerships (PPPs), enhancing access to modern agricultural technologies and practices. The Agricultural and Fisheries Mechanization Law (RA 10601) underscores the importance of adopting mechanization technologies and encourages collaboration with private entities to achieve this objective (Amongo & Larona, 2015). By attracting private sector investments, the government seeks to enhance infrastructure and agricultural capabilities, enabling improved access to essential equipment necessary for modernizing agricultural practices (JICA, 2018). Collaborations between local farming cooperatives and private machinery manufacturers often involve joint initiatives, such as training programs educating farmers on the effective use of agricultural machinery. These programs aim to help farmers maximize the benefits of mechanization, addressing the challenges of integrating new technologies into a traditionally labor-intensive sector (DA, 2024). Nevertheless, challenges like limited access to financing and the fragmented nature of farms can hinder growth. To overcome these obstacles, it is critical to implement policies that support funding and infrastructure development, ensuring sustainable agricultural practices can be enhanced for the agricultural community (ADB, 2024).

Private sector innovation, particularly in agricultural machinery technology and services, is also vital for enhancing agricultural productivity. Collaborations between private companies and the government have led to advancements that improve efficiency while promoting sustainable practices. By emphasizing technological innovation, local farmers are better equipped to meet challenges posed by climate change and increasing market demands. The private sector has significantly contributed to introducing innovations in agricultural machinery tailored to local conditions, reducing reliance on imported foreign machinery and parts. This progress enables local farmers to adopt technology that enhances their operational capabilities and increases crop yields. The partnership between government bodies and private enterprises has resulted in significant progress in agricultural technology, with policies encouraging collaborations to develop locally suited machinery, making it more accessible and affordable for farmers. Research and development (R&D) in the agricultural machinery industry has been a key driver of innovation. The growth of private sector research in the Philippines has been fueled by the increasing profitability of input industries and the plantation sector, alongside government activities that have enhanced the profitability of investments in research. By focusing on R&D, private companies can create machinery and technology that boost productivity while reducing costs for farmers. The push for disruptive technologies in agriculture, such as precision agriculture, IoT devices, and AI-powered

machines, is transforming agricultural practices, leading to improved efficiency and sustainability in food production (DA Press Office, 2022). Furthermore, private firms often provide training programs to ensure farmers can effectively utilize new machinery, critical for a smooth transition to modern agricultural technologies (GAP, 2018). Despite these advancements, challenges remain, including high machinery costs and limited access to credit for smallholder farmers. Future initiatives should focus on improving financing access, enhancing local production capabilities, and fostering partnerships that promote inclusive growth in the agricultural sector. Continued innovation and investment in agricultural machinery are essential for enhancing food security and economic stability in the Philippines.

Lastly, community-based mechanization strategies are vital for enhancing agricultural productivity and sustainability. By emphasizing cooperative models and localized solutions, these strategies empower farmers and promote the efficient use of resources, enabling smallholder farmers to access mechanization without incurring prohibitive costs. Cooperative models significantly advance community-based mechanization by allowing farmers to pool resources, thereby sharing access to expensive machinery that might otherwise be unattainable for individual smallholders. This collaborative approach enhances economies of scale, reducing costs and increasing overall productivity while fostering a sense of community and collaboration among farmers. Within a cooperative framework, farmers can coordinate work schedules, share training in machinery operation, and engage in joint marketing of their products. For instance, local agricultural cooperatives often provide shared machinery services, enabling members to utilize well-maintained equipment for various agricultural tasks (Gilbert, 2015).

Localized solutions involve adapting mechanization strategies to fit the specific contexts and needs of farming communities, accounting for diverse agricultural practices across different regions of the Philippines. By understanding local conditions such as soil types, crop variations, and climatic factors, communities can design mechanization strategies that are more effective and grounded in their unique agricultural realities. Implementing localized mechanization solutions also necessitates engaging local stakeholders in decision-making processes, ensuring that farmers contribute their insights and experiences. This collaborative approach leads to developing machinery and practices that reflect local needs while integrating traditional farming practices with modern technology, thereby improving productivity while preserving cultural heritage (Briones, 2019).

CASE STUDIES

Agricultural mechanization has proven to be a crucial factor in enhancing productivity, addressing labor shortages, and improving sustainability in various regions. In the Philippines, mechanization has significantly boosted efficiency in regions like San Leonardo, Nueva Ecija, where mechanized rice farming improved yields and reduced labor costs (Jesus, 2024). Similarly, small-scale farmers in Leyte adopted intercropping practices, improving soil health and increasing productivity despite limited farm sizes (Enerlan & Bulayog, 2021). Mechanization has been essential in regions like Banganga, Nepal, where labor shortages due to youth outmigration encourage the adoption of machinery, mirroring similar trends in the Philippines (Sunar et al., 2022). Education has also been a key driver of mechanization, with studies showing that educated farmers are more likely to adopt modern machinery (Lanzona, 2013). Climate variability has posed challenges to agriculture in the Philippines, and mechanization supported by initiatives like the Rice Competitiveness Enhancement Fund (RCEF) Mechanization Program has played a vital role in sustaining productivity despite extreme weather (Cayetano et al., 2023). Emerging technologies, such as the Internet of Things (IoT) and agricultural robotics, are reshaping Philippine agriculture by enhancing

efficiency and crop yields, representing a paradigm shift toward cyber-physical systems (Nnoli et al., 2022).

Internationally, best practices in agricultural mechanization provide valuable lessons in productivity, sustainability, and efficiency. In India's Punjab region, government subsidies for tractors and training workshops have driven mechanization in rice and wheat farming, reducing costs and maximizing benefits (Jha et al., 2019). Brazil's public-private partnerships have led to significant investments in modern equipment and irrigation systems, boosting agricultural productivity (Wilkinson, 2016). Sustainable mechanization practices, such as solar-powered irrigation pumps in Kenya, illustrate the integration of renewable energy for long-term success (Hassan, 2018). In the United States, precision agriculture, utilizing GPS-driven tractors and drones, demonstrates the power of data-driven insights in improving yields and reducing waste (Shackelford, 2019). China's focus on small-scale machinery for smallholder farms highlights the need for localized solutions to improve efficiency (Tikuneh et al., 2023). Similarly, South African farmer cooperatives have successfully pooled resources to acquire expensive machinery, showcasing the benefits of collaboration in overcoming economic barriers (Shackelford, 2019).

Table 3. Global Mechanization Strategies and Key Insights in Agriculture

Country/ Region	Area of Focus	Mechanization Strategy	Key Insight
India	Rice and Wheat Production	Government subsidies for tractors	Increased access through training and workshops
Brazil	Agricultural Investment	Public-private partnerships	Enhanced machinery access via collaboration
Kenya	Sustainable Practices	Solar-powered equipment	Improved productivity while conserving resources
USA	Precision Agriculture	GPS technology	Data-driven insights enhance yield
China	Smallholder Support	Tailored small-scale machinery	Custom solutions increase efficiency
South Africa	Cooperative Mechanization	Resource sharing among farmers	Collective approach enables access to high-cost equipment
Netherlands	Climate Adaptation	Automated greenhouses	Mechanization assists in climate resilience
Japan	Automation in Agriculture	Robotics for planting/harvesting	Labor cost reduction through automation
Thailand	Digital Work Models	Telework integration	Remote operations maintain efficiency during crises
Italy	Urban Agricultural Planning	Solar energy integration	Renewable energy optimizes productivity
Canada	Grain Farming	Modern harvesting equipment	Higher yields through advanced equipment
Ghana	Cassava Production	Processing machinery	Enhanced production rates and quality

Mexico	National Agricultural Program	Small-scale mechanization	Inclusive programs benefit smaller farmers
France	Vineyard Management	Mechanized solutions	Optimization of labor use in vineyards
Vietnam	Integrated Farming Systems	Mechanization in multi-crop farms	Resource efficiency and output improvements

Source: World Bank (2008)

The countries like the Netherlands lead in integrating mechanization with climate-adaptive strategies, such as automated greenhouses and resource-efficient irrigation, to enhance resilience against climate change (Shackelford, 2019). In Japan, the use of robotics in farming addresses high labor costs, increasing efficiency. Thailand's adoption of digital tools in hybrid agricultural models during the pandemic highlights the adaptability of mechanization in maintaining efficiency amidst global disruptions (Hassan, 2018). Italy's use of solar energy in urban agriculture underscores the importance of sustainability, reducing dependence on non-renewable resources. Canada's adoption of modern planting and harvesting equipment has revolutionized grain farming, leading to higher yields and better management (Shackelford, 2019). Mechanized cassava processing in Ghana and small-scale mechanization in Mexico show the critical role of machinery in crop production and inclusivity for smallholder farmers. France's mechanized grape harvesting has improved both yield and quality in wine production, while Vietnam's mechanized integrated farming systems in rice and aquaculture demonstrate the transformative impact of technology on diverse farming systems.

These case studies from both the Philippines and abroad illustrate how agricultural mechanization, tailored to local contexts, can drive innovation, improve sustainability, and foster collaboration, providing valuable lessons for the future of global agriculture.

FUTURE DIRECTIONS

The emergence of smart agriculture and farming involves heavily integrating digital technology to increase food production while minimizing input costs. This technology has a significant effect on farmers and investors due to technological advancements (Yasay, 2021). The government has developed a more straightforward approach to farming problems, such as monitoring farm activity through drones, remote sensing, and satellite technologies. Farmers can now access real-time updates on infrastructure and machinery projects from proposal to turning-over through ABEMIS. The use of remote sensing and data analytics has become a game changer in agriculture, especially in weather prediction, forecast of future yields, disaster assessment, and access to insurance schemes available with PRiSM and RIICE projects. Drone use in different applications was strengthened through policies set by the Department of Agriculture (DA). Continuous research for development and technology transfer with local government units through province-led agriculture and fisheries extension systems helps the government promote digital transformation in agriculture. Agriculture 4.0 is considered the future of global agriculture and the engine of agriculture modernization in the Philippines (Cordero & Park, 2023).

Digital technology and innovations, such as e-Kadiwa and data analytics, will be leveraged throughout the food value chain and logistics, starting with the efficient distribution of inputs to farmers enrolled in the Registry System for Basic Sectors in Agriculture (RSBSA). The automated system will improve farm productivity and cut waste by using analytics to facilitate data-driven farming practices for small farmers. Crop

production will be monitored using digital databases to strengthen the digitization of farming and agribusiness activities in the country and pave the way for "Agriculture 4.0" (DA, 2024). The Philippine Rice Research Institute has a number of ICT initiatives. A rice information portal contains key executive information related to rice production with an Android-based mobile application for farm management, weed identification and control, fertilizer recommendation, drones for seeding, and installations of smart farming for irrigation control, and environmental monitoring. This technology is available at different scales of effectiveness and must be workable at the farmer's level with a sense of economic importance.

CONCLUSION

In conclusion, there is a great chance to increase production, improve efficiency, and support sustainable agricultural methods in the Philippines through the mechanization of agriculture. Modern technology must be integrated to boost yields and guarantee farmers' financial security, even if there are regional and crop-specific differences in the existing mechanization state. To fully realize the promise of mechanization, issues including lack of funding, poor infrastructure, and cultural opposition must be resolved.

Using environmentally friendly technology and procedures will guarantee that mechanization has a beneficial effect on rural communities and the environment. To create an enabling environment that supports farmer education and training, facilitates access to funding, and encourages innovation, policymakers, industry partners, and agricultural specialists must work together.

A sustainable agricultural industry will need to strike a balance between the use of new technology and respect for conventional practices as the agricultural environment changes. To increase agricultural output, attain food security, and raise the standard of living for future generations, the Philippines should prioritize automation within a sustainable framework. In the end, a thorough and inclusive strategy will be essential to maximizing mechanization's potential, strengthening rural communities, and promoting sustainable prosperity.

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