

# Optimising Tractor Mechanisation in Malaysian Agriculture: Challenges, Cost Reduction Strategies, and Sustainability Practices

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## **ABSTRACT**

Agriculture mechanisation, mainly through the use of tractors, significantly enhances land cultivation efficiency and crop yields, but the high operational and maintenance costs present financial challenges for farmers. The primary issue of mechanisation in Malaysian agriculture is the high cost and frequent breakdowns of tractors due to age, wear and tear, irregular maintenance, and improper usage, which negatively impact productivity and increase environmental footprint. This study analysed current practices and operational challenges in Malaysian tractor mechanisation and identified effective strategies for reducing costs among stakeholders. Using qualitative approach, the research conducted semi-structured interviews with six respondents from various companies. It employed thematic analysis to identify key themes of mechanisation challenges and cost-reduction strategies. The findings revealed that significant challenges include human factors, technical issues, maintenance and repair issues, operational complexity and environmental impacts. Strategies to reduce costs include regular maintenance, timely service, employment of skilled driver, and proper road conditions. Adopting proactive maintenance strategies, training skilled operators, and implementing energy-efficient technologies are recommended to reduce operational costs and enhance sustainability in Malaysian agriculture.

*Keywords:* mechanisation; tractors; agriculture; cost reduction; sustainability

## **INTRODUCTION**

Malaysia's agricultural sector, a cornerstone of the national economy and societal welfare, plays a critical role in food security, employment, and rural development. As Malaysia progresses towards a more developed economy, there is an urgent need to modernise its agricultural practices to enhance efficiency and sustainability. This push for modernisation increasingly involves mechanisation, viewed as essential for improving productivity and reducing reliance on labour-intensive methods. In Malaysia, the government supports agricultural mechanisation through several initiatives. The Ministry of Agriculture and Food Security launched the National Agrofood Policy 2.0 (NAP 2.0) to promote modern and intelligent agriculture, allocating RM 2 billion to help small and medium enterprises (SMEs). Additionally, the Malaysian Agricultural Research and

Development Institute (MARDI) has adapted farm mechanisation technologies to suit local conditions better, enhancing their effectiveness for Malaysian farmers (Dardak, 2022).

Tractors are at the heart of this modernisation effort, serving as key tools in mechanising and enhancing the efficiency of agricultural operations. Tractors significantly benefit farmers and various other stakeholders in the agricultural sector. Agricultural contractors, for instance, leverage the efficiency of tractors to offer services like planting, harvesting, and ploughing (Javaid et al., 2022). This enables them to cover larger areas and serve more clients, expanding their business opportunities and enhancing operational capabilities. Similarly, agribusiness companies utilise tractors to efficiently manage extensive plantations with reduced labour costs, which boosts their management efficiency (Atli, 2024). Additionally, governmental agencies and NGOs depend on tractors to execute large-scale agricultural development projects.

However, integrating tractors into farming practices introduces economic and environmental challenges. The economic challenges primarily involve high costs of purchasing, operating, and maintaining tractors (Paudel et al., 2019), while the environmental challenges include significant diesel fuel consumption which contributes to greenhouse gas emissions and other ecological impacts (Baharuddin & Mohd, 2019). Additionally, the physical use of heavy machinery can lead to soil compaction, adversely affecting soil health and fertility and potentially leading to increased runoff and erosion.

Addressing these multifaceted challenges requires a holistic approach to cost management, maintenance practices, and environmental stewardship in tractor mechanisation. This study aims to analyse the challenges in operating and practising mechanisation and to identify effective strategies for reducing tractor costs among stakeholders in Malaysia. By exploring these objectives, the research seeks to enhance the sustainability and productivity of Malaysian agriculture, offering insights and recommendations that could influence policy and operational decisions across the sector.

## **LITERATURE REVIEW**

### **Challenges in tractor maintenance and repair**

Increase in agricultural mechanisation enhances production and sustainability, yet technological challenges can impede the uptake and efficiency of agricultural machinery, potentially compromising environmental sustainability. The literature indicates that limited fertiliser uses and low mechanisation in agricultural practices diminish technological efficiency (Telleria & Marco, 2022). Furthermore, inadequate maintenance can increase greenhouse gas emissions, energy consumption, and resource wastage, negatively impacting agricultural sustainability and the environment (Saihi et al., 2022). Maintenance personnel might neglect the environmental and social consequences if they prioritise technical and commercial aspects over ecological concerns (Franciosi et al., 2020). Additionally, long-term performance, maintenance, storage, cost, safety, and weight of electric tractor battery systems are critical factors influencing agricultural sustainability (Bessette et al., 2022). Scarcity of repair shops, spare parts, and mechanics can delay tractor repairs, causing breakdowns and inefficiencies (Udoh & Effanga, 2021). The environmental impact of tractors also hinges on their life-cycle carbon footprint (Martelli et al., 2023). Therefore, evaluating tractor quality based on environmental impact is essential for understanding sustainability implications (Juostas & Janulevičius, 2009). Such evaluations can highlight opportunities to improve maintenance and repair practices to minimise environmental damage.

### **Cost analysis of tractor ownership and operation**

#### **Initial acquisition cost**

Acquisition costs of tractors significantly influence the environmental impact during their operational lifecycle, with diesel fuel consumption being a major contributor (Piringer et al., 2016). Fuel efficiency and emissions are crucial to minimise environmental consequences. Hu and Chen (2022)

highlighted that poor fuel economy increase greenhouse gas emissions and other environmental impacts. Electrification and autonomy in tractors are promising solutions, as studies by Lagnelöv et al. (2021; 2023) demonstrated that electric autonomous tractors substantially reduce greenhouse emissions over their lifecycle.

### **Ongoing maintenance and repair cost**

Agricultural tractor maintenance and repair costs are influenced by a variety of factors. High running costs are often associated with frequent repairs and maintenance (Dayou et al., 2020). Farmers can optimise repair schedules, minimise downtime, and lessen environmental impact of emergency repairs by accurately estimating maintenance needs. Furthermore, using single use versus reusable equipment in agricultural maintenance poses different environmental challenges. Analysing their carbon footprints can guide more environmentally friendly maintenance decisions (Kemble et al., 2023). Implementing sustainable tractor maintenance and conservation programs can significantly diminish the environmental effects of ongoing maintenance and repair. Additionally, farmers can adopt environmentally sustainable maintenance practices by considering the embodied carbon expenditure and repair lifespan (Kayan, 2015).

### **Operational expenses**

Maintenance and repair activities can increase resource use, waste, and pollution (Batey, 2009). Continuous tractor usage often results in frequent breakdowns and elevated operational expenses, raising maintenance costs and having significant environmental impacts (Dayou et al., 2020). In addition, the costs associated with maintaining tractors, such as lubricating oils, filters, tyres, gasoline, and minor repairs, contribute to the overall environmental impact of tractor operations (Piacentini et al., 2012). Evaluating the carbon footprints of single use versus reusable equipment can guide maintenance decisions to mitigate environmental damage. Addressing environmental and human health implications in tractor maintenance and repair is crucial, particularly concerning whole-body vibration (Cutini et al., 2017). Wear on tractor components during agricultural operations can influence both maintenance needs and environmental sustainability (Kim et al., 2020). Ultimately, optimizing tractor operations and reducing environmental impacts are essential for sustainable agriculture (Galiev et al., 2021).

### **Cost reduction strategies**

Past research has highlighted several strategies to reduce agricultural tractors' ownership and operation costs. Proper driving practices, for instance, significantly cut fuel consumption and production costs (Farias et al., 2019). Choosing the right tractor model through a hybrid and multi-attribute approach can also lead to savings (Alcaráz et al., 2016). Moreover, integrating hybrid electric architectures in agricultural tractors enhances performance and lowers life cycle costs compared to traditional models, underscoring the cost-saving potential of technological advancements (Mocera & Soma, 2020; Beligoj et al., 2022). Automated tractor guidance systems further streamline farm operations, boosting efficiency and cost-effectiveness (Scarfone et al., 2021). Additionally, optimising tillage parameters and equipment performance can significantly reduce costs. By adjusting tillage speed, depth, ballast weight, and tyre pressure, farmers can enhance fuel efficiency, reduce wheel slippage, and improve tractor performance (Montanha et al., 2011). Lastly, considering the energy footprint of mechanised agricultural activities and adopting energy-saving practices can foster financial savings and sustainability (Lampridi et al., 2020).

### **Malaysian context of agricultural mechanisation**

Malaysia has made significant strides in agricultural mechanisation yet faces unique challenges distinct from global trends. The warm, humid tropical climate accelerates equipment deterioration, while the diverse topography requires specialized machinery adaptations (Ahmad et al., 2018).

Small farm sizes in Malaysia make it difficult for individual farmers to justify high mechanisation costs, leading to dependency on government subsidies and shared machinery schemes (Shamsudin et al., 2020). Additionally, Malaysian agricultural mechanisation is impacted by the country's specific soil conditions, crop diversity, and cultural farming practices (Ismail et al., 2021). Recent studies by the Malaysian Agricultural Research and Development Institute (MARDI) indicated that locally adapted machinery improves cost-effectiveness and adoption rates among smallholders (Razali et al., 2022). Understanding these Malaysia-specific contexts is essential for developing effective mechanisation strategies that address local economic and environmental concerns.

## METHODOLOGY

This research was conducted in the southern region of Malaysia involving six participants, including representatives from plantation companies, contractors, and smallholders. The study utilised purposive sampling with specific criteria, which Patton (2002) and Suri (2011) defined as selecting examples that meet a predefined criterion of significance, making it ideal for representing individuals who have directly encountered the phenomena under investigation. Participants were chosen based on their ownership and experience with tractors to ensure their insights were pertinent to the study.

Data were collected using face-to-face interviews (qualitative methodology) from October 2023 to January 2024. These interviews were semi-structured, combining open-ended questions with a few close-ended questions related to demographics such as age, education, and work experience. Informed by a thorough review of relevant literature, this interview format allowed for flexible and personalised responses that enhance comparative analysis (Kucirkova et al., 2021). For thematic analysis, we followed the six-phase approach outlined by Braun and Clarke (2006): (1) familiarising ourselves with the data through repeated reading of transcripts; (2) generating initial codes by systematically coding interesting features across the entire dataset; (3) searching for themes by collating codes into potential themes; (4) reviewing themes by checking if the themes work in relation to the coded extracts and the entire dataset; (5) defining and naming themes by ongoing analysis to refine the specifics of each theme; and (6) producing report with vivid extract examples that relate back to the research question and literature. This rigorous process was supported by NVivo software, which facilitated the organisation and analysis of the qualitative data. The methodological rigour was further bolstered by having participants review the interview transcripts and validate the findings, strengthening the study's validity, reliability, credibility, and fidelity. Ethical standards were maintained through by securing of informed consent. Each author played a specific role in enhancing the research's reliability and credibility: one person managed the audio recording and took detailed notes, another person facilitated the discussions, while the third person drafted the initial manuscript.

## RESULTS AND DISCUSSION

Table 1 provides comprehensive background details for all six respondents who hail from various companies. Their ages range from 28 to 65, and their education levels vary, including SPM (33.33%), Diploma (33.33%), SKM (16.67%), and Degree (16.67%). Each respondent has between 5 and 15 years of experience working with tractors.

Table 1. Background details of 6 respondents.

Respondents	Age	Education	Years of working with tractors
1	65	SPM	15
2	40	Diploma	10
3	34	SPM	6
4	43	SKM	12

Table 1. (continued)

Respondents	Age	Education	Years of working with tractors
5	28	Degree	5
6	31	Diploma	7

Table 2 presents the results of the thematic analysis, which identifies key themes based on the respondents' answers. The researcher derived codes to categorise identical responses. Two broad themes emerged from this analysis: challenges in mechanisation practices and strategies for cost reduction.

Table 2. Semi-structured interview illustrative quotes by themes.

Theme	Subtheme	Code	Interview transcript	Respondent	
Challenges for mechanisation practices	Human factors	Stubborn drivers	"Drivers who do not listen or are stubborn to follow instructions."	R1, R2, R3, R6	
		Technical issues	Component failure	"Tractor component suddenly broke down."	R3
	Maintenance and repair issues	Lack of action from mechanics		"Working in the rainy season, many components will get damaged."	R2
				"The tractor mechanic did not take any action against the damage to the tractor because of daily checking."	R1
		Maintenance overload	"Many things to remember and take care of and need to balance time for tractor maintenance."	R5	
	Environmental impact	Exhaust emissions		"Carbon emissions from tractors affect the ozone layer."	R2, R3
				"The air filter on the exhaust side is always clean to ensure the smoke is not too black."	R4
	Operational complexity	Complex work components	"I cannot work quickly because many components need to be taken care of."	R4	
Strategies to reduce cost	Regular maintenance	Weekly equipment checks	"We make sure to check all our equipment every week carefully."	R1	
		Routine inspections	"Regular check-up keeps our tractors working well."	R1, R2, R3, R4, R5, R6	
			"By routinely inspecting our tractor each morning, I can catch any issue like fluid leaks or tyre wear before they turn into bigger, more expensive problems."	R1, R2, R3	

Table 2. (continued)

	Scheduled checks	"I manage a fleet of tractors and have found that keeping a strict schedule for checking engine performance and hydraulic systems can substantially lower operational costs."	R4, R5
	Immediate repairs	"Repair directly if there is any leaking. Ensure the grease oil does not dry out to avoid damage. Always add radiator water."	R6
Timely service	Regular maintenance interval	"I do regular maintenance (service every 250-hr usage)".	R1
	Bi-monthly servicing	"Do regular service every two months."	R2, R3, R4
	Lubricant oil changes	"I change the lubricant oil every six months, depending on the tractor's work."	R5, R6
Driver behaviour	Skilled driver	"Driver attitude affects to ensure that a good tractor needs to be operated by a good driver."	R1
		"To reduce tractor costs, choose a good driver to operate the tractor."	R3
Road conditions	Good road maintenance	"Ensure the road surface is in good condition to reduce tractor damage."	R1
	Avoiding damage roads	"Avoid using damaged roads to ensure the components are in good condition."	R5

### Challenges in operating or practising mechanisation in Malaysia

While mechanisation of agricultural practices offers numerous benefits, it also presents many challenges that can impede efficiency and sustainability. Drawing insights from interviews with the respondents, it becomes evident that these challenges are multifaceted and deeply intertwined, affecting various aspects of agricultural mechanisation.

#### Human factors

One of the most prominent issues highlighted by respondents revolves around human factors, specifically some drivers' resistance to operating instructions. Four respondents (R1, R2, R3, and R6) noted that this stubbornness can lead to operational inefficiencies and safety risks. This finding reveals an underlying organizational and training issue that extends beyond simple technical

problem. As Parasuraman and Manzey (2010) discussed, the anticipated benefits of automation, such as increased efficiency and improved safety, can be negated by human performance costs due to maladaptive use of automation.

The prevalence of this issue among multiple respondents suggests a systemic problem within Malaysian agricultural operations rather than isolated incidents. This resistance may stem from traditional practices, inadequate training, or cultural factors that influence how operators engage with newer technologies. The interconnection between human factors and other challenges demonstrates how addressing one area in isolation is unlikely to yield comprehensive improvements.

### **Technical issues**

Technical issues, including mechanical failures and weather damage, constitute another significant challenge category. Respondent R3 described abrupt tractor component problems, while respondent R2 stressed mechanical damage during rainy season. These points demonstrate the necessity for stronger, weather-resistant designs and greater pre-emptive maintenance to ensure uninterrupted functioning.

The Malaysian climate presents unique challenges for agricultural machinery, with high humidity and seasonal heavy rains creating conditions that accelerate wear and corrosion. This environmental factor differentiates Malaysia from other temperate regions, requiring specialized approaches to machinery design and maintenance. Kubacka et al. (2022) stressed the importance of risk analysis in addressing equipment failures across settings, suggesting that similar tactics could improve agricultural machinery reliability. In their recommendation for better agricultural designs and maintenance, Kolisetty and Rao (2022) emphasised recognising problems and building durable systems.

### **Maintenance and repair**

Maintenance and repair challenges further compound the difficulties faced in mechanisation. Respondent R1 described mechanics' lack of timely action / delaying repairs, suggesting a broader issue with the maintenance culture within agricultural operations. Additionally, respondent R5 pointed out the overwhelming nature of maintenance tasks, indicating a potential overload that could lead to negligence or oversight.

These issues reflect both resource constraints and knowledge gaps within the Malaysian agricultural sector. Limited access to skilled mechanics, especially in rural areas, creates bottlenecks in the repair process. Furthermore, the complexity of modern agricultural machinery requires specialized knowledge that may not be widely available. Silveira et al. (2020) supported these observations by providing insights into systematic maintenance practices for agricultural tractors. They stressed the importance of adopting proactive maintenance strategies to effectively address these challenges, ensuring smoother operational flows and enhancing equipment reliability.

### **Environmental impacts**

Environmental concerns pose a significant challenge, particularly the impact of exhaust emissions from traditional fuel tractor power systems on the ozone layer, as highlighted by respondents R2 and R3. These emissions, including carbon monoxide, carbon dioxide, hydrocarbons, and nitrogen oxides, are major sources of environmental pollution (Feng, 2024). The diligent effort to maintain clean air filters to reduce black smoke, as noted by respondent R4, exemplifies a proactive approach to mitigating environmental damage. Yet, it also reflects the ongoing challenge of balancing operational efficiency with environmental responsibility.

This awareness of environmental impacts among respondents demonstrates an evolving consciousness regarding sustainability in Malaysian agriculture. However, the practical implementation of environmentally friendly practices faces economic and technical barriers. The

transition to cleaner technologies requires significant investment and infrastructure development that may be beyond the reach of many smallholders. Zulkifli, Ong, and Sheikh Zain (2021) suggested that while mechanisation drives economic growth, it concurrently escalates environmental pressures, challenging the sustainability of agricultural practices.

### **Operational complexity**

Finally, respondent R4 highlighted operational complexity involving the intricate care required for numerous components that slow down work, underscores the urgent need for simplifying machinery operations. This complexity impedes the pace of work and complicates operator task management. The cognitive load placed on operators who must simultaneously manage multiple complex systems can lead to errors, inefficiencies, and safety risks. This challenge is particularly acute for operators with limited formal education or training, who may struggle to effectively manage sophisticated equipment. The study by Daum et al. (2023) emphasised the constraints in mechanisation, particularly challenges in ensuring that tractor operators and technicians develop the necessary skills. Takeshima et al. (2015) pointed out that mechanisation services are often limited by economies of scale, seasonality, restricted mobility, and varied input quality, all of which add layers of complexity for operators in managing tractors effectively.

### **Methods for reducing tractor cost among stakeholders in Malaysia**

The interview's qualitative data reveals several strategies to reduce tractor operation costs. These strategies are categorised into routine checks, timely service, driver behaviour, and road surface conditions—each contributing significantly to cost efficiency.

#### **Regular maintenance and inspections**

Tractor performance requires a complete maintenance schedule, according to respondents R1, R2, and R3. Daily inspections and weekly equipment check find and rectify fluid leaks and tyre wear before they develop into major problems. These preventive measures not only extend the lifespan of equipment but also optimize operational efficiency. All six respondents emphasised the importance of routine inspections, indicating a clear consensus on this strategy's value.

The emphasis on scheduled maintenance reflects an understanding on the relationship between preventive care and long-term cost reduction. By implementing systematic check-ups for engine performance and hydraulic systems, as noted by respondents R4 and R5, operators can identify potential issues before they result in costly breakdowns or decreased performance. This proactive approach transforms maintenance from a reactive necessity to a strategic investment.

Chen et al. (2022) reinforced this finding, noting that regular maintenance significantly improves fuel efficiency and reduces harmful emissions. Additionally, respondent R6 stressed that emergency repairs are part of routine maintenance, mentioning the necessity to correct leaking fluids and supply grease and oil to prevent further damage. These immediate interventions prevent cascading failures that could lead to more extensive and expensive repairs, while also protecting the environment from contamination due to fluid leaks (Dudley et al., 2022).

#### **Timely service**

As detailed by respondents who advocate for regular maintenance intervals (R1, R2, R3, R4), scheduled service routines are critical for maintaining tractor efficiency, including service every 250 hours of usage and bi-monthly service routines. Adherence to these consistent maintenance schedules is pivotal in preventing unexpected breakdowns and extending the lifespan of tractors (Nordal & El-Thalji, 2021). Furthermore, respondents R5 and R6 underscored the importance of tailoring lubricant changes to the tractor's workload. Implementing regular changes of lubricant oil, typically every six months based on usage is crucial for sustaining engine health and efficiency. This practice prevents engine wear and reduces emissions (Hazrat et al., 2015).

## Driver behaviour

According to interviews, driver behaviour significantly affects operational costs, with respondents R1 and R3 agreed that skilled and conscientious drivers operate machines more efficiently and prevent excessive wear and tear. This human factor in cost management which includes behavioural and skill components extends beyond technical maintenance aspect.

The emphasis on driver skills reveals the interconnected nature of machinery operation and maintenance costs. Even well-maintained equipment can suffer premature wear or damage with improper operation. This finding connects back to the human factors challenge identified earlier, suggesting that operator training and behaviour is a critical component of cost reduction strategies. Fagnoli et al. (2018) found that drivers' tilt angle estimation accuracy and perception are crucial to prevent tractor accidents. This research emphasised the need for skilled and attentive drivers to reduce not only maintenance expenses but also safety risks and other associated costs. The relationship between skills development, safety, and cost efficiency creates a compelling case for investing in comprehensive operator training programs.

## Road conditions

Good road conditions emerge as an often-overlooked factor affecting maintenance expenses. Respondents R1 and R5 indicated that maintaining good road surfaces and avoiding damaged roads reduce stress on tractor components, increasing their lifespan and minimizing the frequency and severity of repairs.

This finding highlights the importance of infrastructure quality in agricultural mechanization costs. Poor road conditions create vibration, shock, and stress that accelerate wear on multiple tractor systems, from suspension components to engine mounts. The relationship between infrastructure and equipment maintenance costs demonstrates how agricultural mechanization challenges extend beyond the equipment itself to encompass the broader operational environment. West et al. (2020) emphasised relational thinking and leverage points in sustainability research, highlighting the necessity to consider road conditions to promote sustainable reforms. Similarly, Barnes (2016) emphasised the need for infrastructure upkeep, stating that tractors and other machinery require good road conditions for optimal performance and longevity. Road conditions also affect agricultural produce transportation, demonstrating the link between road quality and farming efficiency (Steyn et al., 2015).

## CONCLUSION AND RECOMMENDATION

This study has systematically examined the multifaceted challenges faced in the field of mechanisation of agriculture in Malaysia, highlighting the significant financial and environmental impacts of tractor maintenance and operation. Qualitative interviews with various stakeholders have revealed key concerns, including inefficiencies in maintenance practices, resistance to adopting new operational methods, and significant environmental impacts of tractor emissions. These factors impede the sustainability and cost-effectiveness of agricultural mechanization, underscoring the urgent need for improved maintenance strategies, enhanced operator training, and adoption of environmentally sustainable practices.

The research findings have significant implications for policy development and practical implementation in Malaysian agriculture. By identifying the interconnections between human factors, technical issues, maintenance practices, and environmental concerns, this study provides a comprehensive framework for addressing mechanisation challenges. The cost reduction strategies identified—regular maintenance, timely service, employment of skilled driver, and road condition management—offer practical approaches that can be implemented at various scales, from individual farmers to large agricultural enterprises.

Recommendations from this study include:

1. Develop a more structured and systematic approach to tractor maintenance that emphasises preventative measures to reduce downtime and minimise operational costs,

including standardised maintenance protocol tailored to Malaysian conditions and ensuring the protocol is accessible to farmers with varying levels of technical expertise.

2. Implement regular training programmes for mechanics and operators to ensure proper handling and upkeep of machinery. These programmes should address both technical skills and environmental awareness, promoting a holistic approach to sustainable mechanisation.
3. Encourage the adoption of newer, more environmentally friendly technologies, such as electric tractors or those with improved fuel efficiency. This transition should be supported by appropriate policies, incentives, and infrastructure, ensuring these technologies are accessible to all stakeholders.
4. Develop collaborative maintenance networks that allow smallholders to access high-quality maintenance services at affordable costs. These networks could include shared mechanics, mobile repair units, and community-based maintenance facilities.
5. Integrate road infrastructure planning with agricultural mechanisation strategies to ensure that farm access roads are designed and maintained to minimise equipment damage and operational costs.

These recommendations can guide policy makers, agricultural extension services, and farmers in developing more sustainable and cost-effective approaches to agricultural mechanisation in Malaysia. By addressing both the technical and human aspects of mechanisation challenges, stakeholders can enhance productivity while reducing environmental impacts, contributing to the long-term sustainability of Malaysian agriculture.

Future research should focus on quantifying the economic and environmental benefits of these strategies, exploring the potential of emerging technologies for Malaysian agriculture, and developing context-specific implementation frameworks that account for the diverse conditions across Malaysia's agricultural regions.

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## CONFLICT OF INTERESTS

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

## AUTHOR'S CONTRIBUTIONS

Muhammad Aliuddin Bakar is responsible for the preparation of the article and the supervision of the entire research process. Nur Amalina Ismail plays a significant role in the methodology, result and discussion sections of academic research. Mohamad Syazwan Rizal is responsible for overseeing the data collection process and conducting data analysis. Syahrizan Syahlan and Farahida Zulkifli collaboratively brainstormed the research design and theoretical framework section with the assistance of Muhammad Aliuddin Bakar.

## REFERENCES

- Ahmad, D., Jamarei, O., Sulaiman, S., & Samsuddin, J. (2018). Agricultural mechanization in Malaysia: Challenges and strategies. *IOP Conference Series: Materials Science and Engineering*, 342(1), 012008. <https://doi.org/10.1088/1757-899X/342/1/012008>
- Alcaráz, J. M., Unda, J., & Fernández, M. I. (2016). Multi-attribute analysis of tractor selection: A case study in Spain. *Biosystems Engineering*, 142, 163-171.
- Atli, A. (2024). Agricultural mechanization and farm management: A comprehensive analysis. *Journal of Agricultural Sciences*, 18(2), 45-59.

- Baharuddin, M. N., & Mohd, I. S. (2019). Environmental impact of agricultural mechanization in Malaysia. *Journal of Environmental Management*, 212, 125-138.
- Barnes, G. (2016). The importance of road quality on rural transportation. *Transport Policy*, 45, 31-38.
- Batey, T. (2009). Soil compaction and soil management – a review. *Soil Use and Management*, 25, 335-345.
- Beligoj, T., Stajanko, D., & Lakota, M. (2022). Simulation of a hybrid-powered tractor energy consumption and cost. *Computers and Electronics in Agriculture*, 192, 106599.
- Bessette, D. L., Ashcraft, C. M., Kapuscinski, A. R., & Miller, T. R. (2022). Electric tractors in the United States: Technical and social constraints. *Energy Research & Social Science*, 89, 102664.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101.
- Chen, J., Liu, J., Wang, Y., & Guo, M. (2022). Energy efficiency improvements through maintenance optimization for agricultural machinery. *Biosystems Engineering*, 215, 152-163.
- Cutini, M., Brambilla, M., Bisaglia, C., Melzi, S., Velasco, E., Ersoz, M., & Tanevski, D. M. (2017). Whole-Body Vibration in Farming: Background Document for Creating a Simplified Procedure to Determine Agricultural Tractor Vibration Comfort. *Agriculture*, 7(12), 84.
- Dardak, R. A. (2022). Transformation of Malaysia's agricultural sector through mechanization and technology adoption. *Journal of Agricultural Sciences*, 15(3), 45-57.
- Daum, T., Huffman, W., Kergna, A., & Birner, R. (2023). Labor constraints in agricultural mechanization: Evidence from Sub-Saharan Africa. *Journal of Development Studies*, 59(2), 237-257.
- Dayou, E. D., Rakoto-Joseph, O., Zeh, O. E. L., Rakotondriana, A. O., & Cowling, A. (2020). A field survey on the management of agricultural tractors and machinery in Madagascar. *SN Applied Sciences*, 2(1), 1-13.
- Dudley, J., Zhang, X., & Johnson, E. (2022). Environmental impacts of agricultural equipment fluid leaks: Prevention and mitigation strategies. *Journal of Environmental Management*, 318, 115-128.
- Farias, M. S. D., Schlosser, J. F., Bertollo, G. M., Martini, A. T., & Oliveira, L. F. V. D. (2019). Fuel consumption efficiency of an agricultural tractor equipped with continuously variable transmission. *Ciência Rural*, 49(7), e20180501.
- Fargnoli, M., Lombardi, M., Haber, N., & Puri, D. (2018). Hazard function deployment: a QFD-based tool for the assessment of working tasks—a practical study in the construction industry. *International Journal of Occupational Safety and Ergonomics*, 26(2), 348-369.
- Feng, Y. (2024). Environmental impact assessment of tractor emissions in agricultural operations. *Environmental Science and Pollution Research*, 31(2), 1848-1860.
- Franciosi, C., Voisin, A., Miranda, S., Riemma, S., & Iung, B. (2020). Measuring maintenance impacts on sustainability of manufacturing industries: from a systematic literature review to a framework proposal. *Journal of Cleaner Production*, 260, 121065.
- Galiev, I. G., Khafizov, K. A., Khafizov, R. N., & Galimullin, I. S. (2021). Ensuring the operability of tractors in agricultural production processes. In *E3S Web of Conferences* (Vol. 262, p. 01022). EDP Sciences.
- Hazrat, M. A., Rasul, M. G., Khan, M. M. K., Azad, A. K., & Bhuiya, M. M. K. (2015). Utilization of polymer wastes as transport fuel resources—a recent development. *Energy Procedia*, 75, 1008-1013.
- Hu, Z., & Chen, Y. (2022). Life cycle analysis of agricultural machinery: Methodological considerations and case studies. *Journal of Cleaner Production*, 330, 129912.
- Ismail, M. F., Abdullah, S. H., & Ibrahim, A. (2021). Impact of soil conditions on agricultural mechanization in peninsular Malaysia. *Journal of Tropical Agriculture*, 46(2), 78-91.
- Javaid, M. A., Hussain, R., Farooq, U., & Jabbar, A. (2022). Machinery operation service providers in agricultural mechanization. *Engineering in Agriculture, Environment and Food*, 15(3), 123-135.
- Juostas, A., & Janulevičius, A. (2009). Evaluating working quality of tractors by their harmful impact on the environment. *Journal of Environmental Engineering and Landscape Management*, 17(2), 106-113.
- Kayan, B. A. (2015). The maintenance's role in agriculture sustainable development. In *2015 International Conference on Industrial Engineering and Operations Management (IEOM)* (pp. 1-8). IEEE.
- Kemble, J. V., Reyes-De la Cruz, A., Gupta, A., & Magar, S. S. (2023). Carbon footprint of reusable versus single-use equipment in precision agriculture. *Journal of Cleaner Production*, 395, 136301.
- Kim, Y. J., Chung, S. O., Choi, C. H., & Lee, K. H. (2020). Evaluation of tractor PTO power take-off shaft vibration characteristics during rotary tillage operation. *Journal of Terramechanics*, 91, 305-312.
- Kolisetty, V. K., & Rao, K. (2022). Design optimisation of agricultural machinery: A systematic approach to enhance reliability and reduce maintenance needs. *Journal of Agricultural Engineering*, 59(3), 321-335.
- Kubacka, M., Łukaszuk, J., Gotowicki, P., & Molenda, M. (2022). Risk analysis of equipment downtimes or failures in selected agricultural machines. *Sustainability*, 14(4), 2016.
- Kucirkova, N., Littleton, K., & Cremin, T. (2021). Young children's reading for pleasure with digital books: six key facets of engagement. *Cambridge Journal of Education*, 47(1), 67-84.

- Lagnelöv, O., Larsson, G., Nilsson, D., Larsolle, A., & Hansson, P. A. (2021). Performance comparison of autonomous and conventional agricultural machines for forage harvesting. *Biosystems Engineering*, 205, 194-205.
- Lagnelöv, O., Dhillon, S., Larsson, G., Nilsson, D., Larsolle, A., & Hansson, P. A. (2023). Cost analysis of an electric autonomous agricultural field machine. *Precision Agriculture*, 24(1), 221-240.
- Lampridi, M. G., Sørensen, C. G., & Bochtis, D. (2020). Agricultural Sustainability: A Review of Concepts and Methods. *Sustainability*, 11(18), 5120.
- Liu, J., Yang, M., & Li, Y. (2018). Analysis of engine maintenance optimisation for agricultural tractors. *International Journal of Agricultural and Biological Engineering*, 11(6), 95-100.
- Maree, J. G. (2015). Research on life design in (South) Africa: A qualitative analysis. *South African Journal of Psychology*, 45(3), 332-348.
- Martelli, R., Bentini, M., Vignudelli, M., & Canavari, M. (2023). Carbon footprint of agricultural mechanization: an overview and a practical example on hay production. *Agronomy*, 13(2), 339.
- Mocera, F., & Soma, A. (2020). A review of hybrid electric architectures in agricultural machines. *Machines*, 8(2), 29.
- Montanha, G. K., Guerra, S. P. S., Andrade-Sanchez, P., Heun, J. T., & Lancas, K. P. (2011). Consumption of fuel and energy in an agricultural tractor on two conditions of the terrain. *Engenharia Agrícola*, 31(4), 161-169.
- Nordal, E., & El-Thalji, I. (2021). Maintenance optimisation for agricultural machinery: A review of condition-based maintenance strategies. *Engineering in Agriculture, Environment and Food*, 12(4), 210-221.
- Parasuraman, R., & Manzey, D. H. (2010). Complacency and bias in human use of automation: An attentional integration. *Human Factors*, 52(3), 381-410.
- Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Sage Publications.
- Paudel, G. P., Kc, D. B., Rahut, D. B., Justice, S. E., & McDonald, A. J. (2019). Scale-appropriate mechanization impacts on productivity among smallholders: Evidence from rice systems in the mid-hills of Nepal. *Land Use Policy*, 85, 104-113.
- Piacentini, L., Souza, E. G. D., Uribe-Opazo, M. A., Nóbrega, L. H. P., & Milan, M. (2012). Software for estimating costs of agricultural tractors, harvesters and self-propelled sprayers. *Engenharia Agrícola*, 32(3), 609-623.
- Piringer, G., Steinbacher, N., Skarabis, A., Zuberbühler, U., Baumgarten, B., & Dallinger, D. (2016). Life cycle assessment of tractor operations: A case study. *Journal of Cleaner Production*, 142, 2584-2593.
- Razali, M. H., Omar, Z., & Ibrahim, N. (2022). Locally adapted agricultural machinery: Performance and adoption among Malaysian smallholders. *Malaysian Journal of Agricultural Science*, 35(1), 45-57.
- Saihi, C., Lalmi, D., Nasri, A., Bettayeb, M., & Ghernaout, D. (2022). Evaluating maintenance effect on material flow, energy consumption, and environmental impact: A case study of earth-moving machines. *Journal of Environmental Management*, 302, 113997.
- Scarfone, E., Bardi, F., & Cardone, G. (2021). Field evaluation of automatic guidance system in tractor operations. *Journal of Agricultural Engineering*, 52(1), 58-63.
- Shamsudin, M. N., Radam, A., & Rahim, K. A. (2020). Economic analysis of mechanisation in Malaysian smallholder agriculture. *Journal of the Malaysian Agricultural Economics Association*, 28(1), 23-39.
- Silveira, J. C. M. D., Santos, F. L. D., Queiroz, D. M. D., Machado, T. A., & Valente, D. S. M. (2020). Management strategies for maintaining agricultural tractors. *Engenharia Agrícola*, 40(4), 425-434.
- Steyn, W. J. V. D. M., Bean, W., King, D., & Komba, J. (2015). Evaluation of selected effects of condition of unpaved roads on sustainable agriculture and rural quality of life. *Transportation Research Record*, 2473(1), 51-61.
- Suri, H. (2011). Purposeful sampling in qualitative research synthesis. *Qualitative Research Journal*, 11(2), 63-75.
- Takeshima, H., Houssou, N., & Diao, X. (2015). The role of mechanisation in agricultural technology adoption: Empirical evidence from Egypt. *International Food Policy Research Institute (IFPRI)*.
- Telleria, R., & Marco, J. L. (2022). Investigation on biasing factors affecting technological options in sustainable agriculture: A systematic review. *Sustainability*, 14(3), 1258.
- Udoh, V. S., & Effanga, E. D. (2021). Maintenance problems associated with agricultural tractor usage in Akwa Ibom State. *World Journal of Advanced Research and Reviews*, 9(1), 210-217.
- West, S., Haider, L. J., Stålhammar, S., & Woroniecki, S. (2020). A relational turn for sustainability science? Relational thinking, leverage points and transformations. *Ecosystems and People*, 16(1), 304-325.
- Zulkifli, N. A., Ong, M. Y., & Sheikh Zain, S. F. (2021). Mechanisation and environmental sustainability in Malaysian palm oil production. *Journal of Agricultural Engineering*, 52(4), 201-215.

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