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

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DOI: https://doi.org/10.47772/IJRISS.2026.100800113

Received: 10 August 2026; Accepted: 11 August 2026; Published: 27 August 2026

ABSTRACT

Agriculture mechanisation, mainly through tractors, significantly enhances land cultivation efficiency and crop yields, but the high operational and maintenance costs present financial challenges for farmers. The primary issue 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 analyses Malaysian agriculture's operational challenges and mechanisation practices and identifies effective strategies for reducing tractor costs among stakeholders. Using a qualitative approach, the research conducts semi-structured interviews with six respondents from various companies. It employs thematic analysis to identify key themes of mechanisation challenges and cost-reduction strategies. The findings reveal 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 servicing, skilled driver behaviour, and maintaining good road conditions. Adopting proactive maintenance strategies, training skilled operators, and implementing energy-efficient technologies to reduce operational costs and enhance sustainability in Malaysian agriculture is recommended.

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 (Atlı, 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 the high costs of purchasing, operating, and maintaining tractors

(Paudel et al., 2019). Environmentally, the deployment of tractors is linked to concerns such as 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

Increasing 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, higher energy consumption, and resource wastage, negatively impacting agricultural sustainability and the environment (Saihi et al., 2022). Maintenance stakeholders might neglect the environmental and social consequences if they prioritise technical and commercial aspects over ecological concerns (Franciosi et al., 2020). Additionally, the long-term performance, maintenance, storage, cost, safety, and weight of electric tractor battery systems are critical factors influencing agricultural sustainability (Bessette et al., 2022). A 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

The 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). Thus, fuel efficiency and emissions are crucial to minimise environmental consequences during acquisition. Hu and Chen (2022) highlight that a poor fuel economy intensifies the life cycle of greenhouse gas emissions and other environmental impacts. Electrification and autonomy in tractors are promising solutions, as studies by Lagnelöv et al. (2021; 2023) demonstrate 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 the 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 impact are essential for sustainable agriculture (Galiev et al., 2021).

Cost Reduction Strategies

Research highlights 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 mechanized agricultural activities and adopting energy-saving practices can foster financial savings and sustainability (Lampridi et al., 2020).

METHODOLOGY

This research was conducted in the southern region of Malaysia with six participants, including representatives from plantation companies, contractors, and smallholders. The minimum number of respondents is four, which is necessary to get a clear picture of the issues faced (Maree, 2015). The sample size is consistent with the depth-oriented aims of qualitative inquiry, although it limits the extent to which the findings can be generalised to the wider population of agricultural stakeholders. The study utilised purposive sampling with specific criteria, which Patton (2002) and Suri (2011) define 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 that employed a qualitative methodology from October 2023 to January 2024. These interviews were semi-structured, combining open-ended questions with a few closed 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 enhanced comparative analysis (Kucirkova et al., 2021). 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 the securing of informed consent. Each author played a specific role in enhancing the research's reliability and credibility: one managed the audio recording and took detailed notes, another facilitated the discussions, and a third drafted the initial manuscript. The collaborative effort also encompassed data coding and topic identification through thematic analysis, utilising NVivo software for data analysis.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue VIII August 2026

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. The respondents were drawn from plantation companies, contractors, and smallholder operations; some worked mainly as tractor operators, while others were also responsible for supervising machinery and managing a fleet of tractors. This mix of roles allowed the study to capture both hands-on operating experience and management-level views on maintenance and cost.

Table 1: Background Details of 6 Respondents

Respondents	Age	Education	Role / type of operation	Years of working with tractors
1	65	SPM	Smallholder	15
2	40	Diploma	Plantation company	10
3	34	SPM	Contractor	6
4	43	SKM	Plantation company	12
5	28	Degree	Contractor	5
6	31	Diploma	Smallholder	7

Table 2 presents the results of a 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 of practices Mechanization	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." "Working in the rainy season, many components will get damaged."	R3 R2
	Maintenance and repair issues	Lack of action from mechanics	"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." "The air filter on the exhaust side is always clean to ensure the smoke is not too black."	R2, R3 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." "By routinely inspecting our tractor each morning, I can catch any issues like fluid leaks or tyre wear before they turn into bigger, more expensive problems."	R1, R2, R3, R4, R5, R6 R1, R2, R3
		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 Servicing	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 behavior	Skilled driver	"Drive attitude affects to ensure that a good tractor needs to be operated by a good driver."	R1 R3

			"To reduce tractor costs, choose a good driver to operate the tractor."	
	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

Theme 1: The Challenges in Operating or Practising Mechanisation in Malaysia

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

Human factors

One of the most prominent issues highlighted by respondents revolves around human factors, specifically some drivers' resistance to operating instructions. Respondents R1, R2, R3, and R6 noted that this stubbornness can lead to operational inefficiencies and safety risks. Parasuraman and Manzey (2010) discuss how the anticipated benefits of automation, such as increased efficiency and improved safety, can be negated by human performance costs due to the maladaptive use of automation.

Technical issues

Technical issues, including mechanical failures and weather damage, are also important. Respondent R3 described abrupt tractor component problems, while Respondent R2 stressed mechanical damage during the rainy season. These occurrences demonstrate the necessity for stronger, weather-resistant designs and greater pre-emptive maintenance to ensure uninterrupted functioning.

Kubacka et al. (2022) stress 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) emphasise recognising problems and building durable systems.

Maintenance and repair

Maintenance and repair issues further compound the challenges faced in mechanisation. Respondent R1 described mechanics' lack of timely action as delaying repairs and 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. Silveira et al. (2020) support these observations by providing insights into systematic maintenance practices for agricultural tractors. They stress the importance of adopting proactive maintenance strategies to effectively address these challenges, ensuring smoother operational flows and enhancing equipment reliability.

Environmental impact

Environmental concerns pose a significant challenge, particularly the impact of exhaust emissions from traditional fuel tractor power systems on the ozone layer, highlighted by respondents R2 and R3. These emissions, including carbon monoxide, carbon oxides, 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 R4, exemplifies a proactive approach to mitigating environmental damage. Yet, it also reflects the ongoing challenge of balancing operational efficiency with environmental responsibility. Zulkifli, Ong, and Sheikh Zain (2021) findings suggest that while mechanisation drives economic growth, it concurrently escalates environmental pressures, challenging the sustainability of agricultural practices.

Operational complexity

Finally, the operational complexity highlighted by respondent R4, 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 study by Daum et al. (2023) emphasises the constraints in mechanisation, particularly the challenges in ensuring that tractor operators and technicians develop the necessary skills. Takeshima et al. (2015) points out that mechanization 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.

Theme 2: Method for Reducing Tractor Cost Among Stakeholder in Malaysia

The interview's qualitative data reveals several strategies to reduce tractor operation costs. These strategies are categorised into routine checks, timely servicing, driver behaviour, and road surface conditions, each contributing significantly to cost efficiency. It is worth noting that the costs described by respondents are not of a single kind: they cover routine maintenance costs such as lubricants, filters and grease; repair expenses following breakdowns; fuel costs linked to machine condition and driving behaviour; and losses arising from downtime when a tractor is out of service. Although respondents rarely separated these categories explicitly, distinguishing between them helps to clarify where each of the strategies below delivers its savings.

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. Weekly equipment checks prevent costly repairs and downtime by spotting issues early. These tests boost fuel efficiency and reduce emissions (Chen et al., 2022). 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. Repair leaks and fluid levels immediately to protect the environment and machinery (Dudley et al., 2022). Daily inspections detect fluid leaks and tyre wear early, improving operation and reducing emissions (Airoldi et al., 2020). Respondents R4 and R5 also highlight planned engine performance and hydraulic system checkups to avert major mechanical faults and lower operational costs. Tractor engines and hydraulic systems must be periodically examined to maximise fuel economy and reduce emissions (Liu et al., 2018).

Timely Servicing

Scheduled servicing routines are critical for maintaining tractor efficiency, as detailed by respondents who advocate for regular maintenance intervals, including service every 250 hours of usage and bi-monthly service routines (R1, R2, R3, R4). 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 underscore 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. Respondents R1 and R3 agree that skilled and conscientious drivers operate machines efficiently and prevent excessive wear and tear, avoiding costly repairs. Fargnoli et al. (2018) found that drivers' tilt angle estimation accuracy and perception are crucial to preventing tractor accidents. This emphasises the need for skilled and attentive drivers to reduce maintenance expenses. Tractor operation depends on the driver's attitude and skill.

Road Conditions

Good road conditions can affect maintenance expenses. Respondents R1 and R5 indicate that maintaining good road conditions and avoiding damaged roads reduce tractor component stress, increasing their lifespan and minimising repair frequency and severity. West et al. (2020) emphasise relational thinking and leverage points in sustainability research, emphasising the necessity to consider road conditions to promote sustainable reforms. Barnes (2016) emphasises the need for infrastructure upkeep, stating that tractors and other machinery need good road conditions. Road conditions also affect agricultural produce transportation, demonstrating the link between road quality and farming efficiency (Steyn et al., 2015).

CONCLUSION AND RECOMMENDATIONS

This study has systematically examined the multifaceted challenges faced in the 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 the 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 adopting environmentally sustainable practices.

Recommendations from this study include developing a more structured and systematic approach to tractor maintenance that emphasises preventative measures to reduce downtime and operational costs. Regular training programs for mechanics and operators are also recommended to ensure proper handling and upkeep of machinery; such programmes should cover proper driving techniques, routine daily inspection, fuel-efficient operation, and the early recognition of mechanical faults before they develop into major breakdowns. Furthermore, encouraging the adoption of newer, more environmentally friendly technologies, such as electric tractors or those with improved fuel efficiency, is essential. This shift will help reduce the carbon footprint associated with traditional diesel-powered tractors and align with global sustainability goals.

As a qualitative study based on six respondents in the southern region of Malaysia, the findings offer depth of insight rather than statistical generalisability. Future research should therefore involve a larger and more varied group of stakeholders, including machinery dealers, maintenance providers, and officers from agricultural agencies, to test whether the themes identified here hold more widely. There is also room to complement these qualitative findings with quantitative data on tractor age, annual operating hours, fuel consumption, breakdown frequency, maintenance expenditure, and repair duration, so that the factors contributing most to overall operating cost can be measured directly. Such data would in turn support the development of a preventive or predictive maintenance framework in which servicing is scheduled according to actual usage and failure patterns rather than fixed intervals, allowing farmers to plan servicing before major breakdowns occur.

ACKNOWLEDGEMENT/FUNDING

The authors would like to acknowledge the support of Universiti Teknologi Mara (UiTM), Cawangan Melaka, Kampus Jasin and Faculty of Plantation and Agrotechnology, Universiti Teknologi MARA, Jasin, Melaka, Malaysia for providing the facilities on this research.

Conflict of Interest Statement

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.

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