Short Article

Investigating the Effect of Tillage Patterns, Operating Speeds, and Plough Types on the Performance of Mini Hand Tractors in Border Wetlands

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Abstract

The performance of mini hand tractors is crucial for improving productivity and operational efficiency in wetland rice farming. This study aimed to evaluate the effects of plough type, tillage pattern, and operating speed on mini hand tractor performance in the border region of Tarakan, Indonesia. Field experiments were conducted from September 2024 to January 2025 using a factorial design (3×5×2) and quantitative descriptive analysis supported by SPSS Statistics 26 for numerical comparison. Performance indicators included wheel slip (%), field efficiency (%), fuel consumption (L h^{-1}), and engine temperature (°C). Results showed that the rotary plough operating under the central tillage pattern at low speed (1 m s^{-1}) achieved the highest field efficiency (78%) and the lowest fuel consumption (1.306 L h^{-1}). In contrast, the disc plough with the central border pattern at high speed (2.3 m s^{-1}) produced the highest wheel slip (48%) and lowest efficiency (22%), indicating substantial performance losses due to excessive soil–wheel friction. Engine temperature increased proportionally with tractor speed, reaching up to 70 °C during high-speed operations. These findings demonstrate that optimising plough type and tillage pattern selection can enhance tractor efficiency by up to 56%, reduce fuel use by 0.8 L h^{-1}, and improve operational stability in wetland conditions. The study provides practical recommendations for selecting and operating mini hand tractors to enhance energy efficiency and sustainability in wetland mechanisation systems across Southeast Asian border regions.

Keywords: Border region, Mini hand tractor, Performance evaluation, Tillage system, Wetlands

Introduction

Agriculture remains one of the most critical sectors for sustaining global food security, especially amid the dual pressures of population growth and climate change. Enhancing productivity while maintaining environmental sustainability has become a key priority in modern agricultural systems (Cole, Augustin, Robertson, & Manners, 2018; Pawlak & Kołodziejczak, 2020; Viana, Freire, Abrantes, Rocha, & Pereira, 2022). Wetlands constitute an important yet challenging agricultural resource, characterised by high soil moisture and poor bearing capacity that hinder the operation of conventional tractors (Ding, Qi, Chen, Mei, & Li, 2025; Evans *et al.*, 2023; Gamage *et al.*, 2023; Slater, 2021). These conditions often cause machinery to sink or lose traction, resulting in inefficiencies in land preparation and increased operational costs.

Mini hand tractors have emerged as an effective solution for smallholder farmers operating under such conditions due to their lightweight structure, manoeuvrability, and affordability (Chartres & Noble, 2015; Daum, Seidel, Awoke, & Birner, 2023; Liu *et al.*, 2025; Marambanyika, 2015; Singh & Nath, 2020). However, the performance of these machines in wetland environments depends heavily on soil tillage patterns, plough design, and operational speed that influence traction, soil disturbance, and fuel efficiency. Despite the growing attention to small-scale mechanisation, comprehensive evaluations of these interacting parameters under wetland conditions remain limited

(Singh & Nath, 2020).

Previous studies have mainly focused on optimising plough design or analysing soil-machine interactions in dryland or upland contexts (Clark & Tilman, 2017; Shah & Wu, 2019; Khodabakhshi, Kalantari, & Mousavi, 2013), leaving a gap in understanding how combinations of plough types, tillage patterns, and tractor speeds affect performance in wet soils. Addressing this gap is crucial for developing adaptive mechanisation strategies that are both technically efficient and environmentally sustainable (Bhooshan *et al.*, 2024; Herranz-Matey, 2025; Iram, Iqbal, Ahmad, & Jaffri, 2020; Salam, Fikry, & Rizali, 2024; Santoso *et al.*, 2025). In Indonesia's border regions, such as North Kalimantan, farmers face additional constraints, including limited access to modern equipment, weak infrastructure, and high costs of machinery importation (Santoso *et al.*, 2025; Tahcfulloh, Wahyuni, Santoso, & Anam, 2024; Wahyuni, Sutrisno, Santoso, & Egra, 2023). Under these conditions, mini hand tractors offer a practical alternative to improve productivity and reduce manual labour. Yet, their optimal configuration for wetland use remains underexplored.

Therefore, this research aims to comprehensively analyse the performance of mini hand tractors in wetland agriculture by evaluating the combined effects of plough types (Single Furrow, Rotary, and Disc Plough), soil tillage patterns (Central, Tight, Edge, Central Border, and Spiral), and tractor speeds (low and high). Unlike previous studies that examined these factors separately, this research integrates them within a unified experimental framework to provide new insights into adaptive mechanisation strategies for Indonesia's border wetlands. The findings are expected to guide farmers, engineers, and policymakers in optimising mechanised land preparation for improved productivity and efficiency.

Materials and Methods

This research was conducted from September 2024 to January 2025 in agricultural fields in Tarakan city, North Kalimantan, Indonesia. The equipment used in this research includes a hand tractor, a stopwatch, a meter, writing tools, documentation tools, an optic tachometer, an industrial infrared thermometer, and Sigmaplot software. The material used was diesel fuel (solar). The research procedure consists of several stages, as shown in Figure 1.

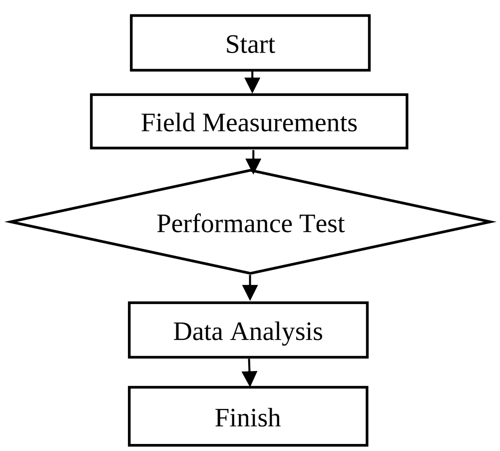

Fig. 1. Research procedure flowchart

The purpose of performance testing is to assess the optimal operation of the hand tractor. Before testing the hand tractor, a functional test was conducted to ensure that components such as levers, brakes, and the hand tractor engine operate according to their intended functions. The following are the steps in the hand tractor testing process:

1. Fill the tractor's fuel tank to its full capacity.
2. Inspect the condition of the tractor, verify the completeness of research instruments, and assess the condition of the land.
3. Start the tractor engine.
4. Record the temperature before operating the hand tractor.
5. Operate the hand tractor for soil cultivation with a border pattern, at predetermined speeds of 1 m s^{-1} and 2.3 m s^{-1}, in accordance with the specifications of the mini hand tractor. Soil is processed using a single plough.
6. During the soil processing process, measure the rotation of the hand tractor's wheels (in meters) and the actual working width (in metres).
7. After completing the cultivation of a plot, the operator turns off the engine and refills the hand tractor's fuel tank to its full capacity. This is done to determine fuel consumption during the processing.
8. After finishing the land processing, record the temperature after the operation at each different speed.
9. Soil cultivation activities are repeated three times for each different treatment.
10. The soil processing activity is repeated three times for each respective treatment.

To ensure consistency in field operations, the ploughing depth was set and controlled at 20 cm across all treatments by adjusting the blade penetration depth equally for each plough type. This constant depth setting was maintained throughout the experiment to minimise variability and ensure reliable performance comparisons between plough types, tillage patterns, and operating speeds.

Data collection for this research was carried out in Mamburungan Village, East Tarakan District, Tarakan City, North Kalimantan (Figure 2). Specifically, it was conducted in the fields of the Mapan Sejahtera Farmer Group, using a hand tractor equipped with three types of ploughs: single furrow plough, rotary plough, and disc plough (Figure 3). Various soil tillage patterns were tested, including the central, tight, edge, spiral, and central border patterns. Two tractor speeds were used: low (1 m s^{-1}) and high (2.3 m s^{-1}). Each treatment was replicated three times, resulting in a total of 90 repetitions. The type of land used in this study was wetland, specifically paddy fields, with three plots of land measuring 30 m × 15 m. Data analysis in this study used a simple quantitative descriptive approach. All raw data obtained from field measurements were processed using Microsoft Excel 2021. Each parameter, including wheel slip, fuel consumption, field efficiency, and engine temperature, was averaged from several replications. The mean values were then compared descriptively to observe performance trends among different plough types, tillage patterns, and tractor speeds.

Fig. 2. Land and tractor used in this research

(a) (b) (c)

Fig. 3. Three plough types used: (a) Single furrow, (b) Disc, and (c) Rotary plough

Results and Discussion

This section presents the findings of the study analysing the performance of a mini hand tractor under various speed and ploughing conditions. The test results are presented in Table 1 and Figure 4.

The analysis was based on key performance parameters, including wheel slip (%), actual speed (m s^{-1}), theoretical speed (m s^{-1}), theoretical field performance (ha h^{-1}), actual field performance (ha h^{-1}), performance efficiency (%), fuel consumption (L h^{-1}), and engine temperature (°C).

The results indicate that the lowest wheel slip (12%) was recorded when using a rotary plough with the central pattern tillage method at low speed, demonstrating its effectiveness in maintaining traction and minimising energy losses. In contrast, the highest wheel slip (48%) was observed with the disc plough using the central border pattern at high speed, which led to reduced field efficiency and increased fuel consumption. Furthermore, the highest field efficiency (78%) was achieved with the rotary plough in the central pattern at low speed, while the lowest fuel consumption (1.306 L h^{-1}) was also recorded under the same conditions.

Further analysis reveals that the selection of plough type and tillage pattern significantly influences the overall performance of the mini hand tractor. The disc plough, despite its deeper penetration capability, exhibited higher wheel slip, particularly at high speeds, which can negatively affect traction and increase energy expenditure. On the other hand, the rotary plough demonstrated superior adaptability in wet soil conditions, reducing resistance and improving operational stability. Additionally, variations in fuel consumption and engine temperature across different treatments suggest that optimising ploughing strategies can lead to more efficient and sustainable farming practices. These findings highlight the importance of selecting the appropriate ploughing equipment and tillage method to maximise tractor performance while minimising energy losses and environmental impact.

Table 1- Results of performance analysis

Plough Type	Tillage Pattern	Speed	Test Result							
			Wheel Slip (%)	**Actual Speed (m s^{-1})**	**Theoritical Speed (m s^{-1})**	**Theoretical Field Performance (Ha h^{-1})**	**Actual Field Performance (Ha h^{-1})**	**Performance Eficiency (%)**	**Fuel Consumption (L h^{-1})**	**Engine Temperature (ºC)**
Single Furrow Plough	Central	Low	28	0.440	0.996	0.359	0.128	36%	1.611	54.350
		High	45	0.460	1.873	0.476	0.312	66%	2.187	56.780
	Tight	Low	18	0.640	0.766	0.221	0.124	56%	1. 385	52.580
		High	24	0.350	1.005	0.359	0.231	64%	2.155	57.440
	Edge	Low	20	0.360	0.890	0.476	0.311	65%	2.330	56.555
		High	35	0.410	0.782	0.227	0.103	45%	2.193	57.062
	Central Border	Low	22	0.370	0.674	0.222	0.105	47%	2.552	57.569
		High	28	0.400	0.566	0.489	0.312	64%	1.984	58.076
	Spiral	Low	20	0.278	0.660	0.254	0.093	37%	2.444	59.255
		High	20	0.278	0.660	0.254	0.093	37%	2.444	59.255
Rotary Plough	Central	Low	12	0.770	1.225	0.333	0.244	73%	1.306	52.330
		High	35	0.460	1.873	0.402	0.080	20%	2.187	65.330
	Tight	Low	18	0.300	0.887	0.471	0.084	18%	1.355	53.740
		High	24	0.350	1.143	0.540	0.089	16%	1.327	59.440
	Edge	Low	20	0.280	1.089	0.277	0.093	34%	1.763	60.145
		High	35	0.410	1.034	0.281	0.098	35%	1.333	61.119
	Central Border	Low	22	0.370	0.980	0.277	0.102	37%	1.344	68.930
		High	20	0.278	0.660	0.254	0.093	37%	2.444	59.255
	Spiral	Low	20	0.360	0.890	0.476	0.311	65%	2.330	56.555
		High	37	0.348	0.659	0.312	0.102	33%	1.762	53.885
Disc Plough	Central	Low	28	0.120	0.726	0.277	0.076	27%	1.722	65.300
		High	33	0.210	0.788	0.361	0.080	22%	1.906	70.020
	Tight	Low	18	0.190	0.559	0.244	0.084	35%	1.666	55.390
		High	24	0.243	0.502	0.495	0.089	18%	1.612	64.210
	Edge	Low	20	0.278	0.660	0.254	0.093	37%	2.444	59.255
		High	35	0.313	0.500	0.287	0.098	34%	2.204	57.465
	Central Border	Low	37	0.348	0.659	0.312	0.102	33%	1.762	53.885
		High	48	0.383	0.611	0.278	0.106	38%	1.693	55.675
	Spiral	Low	20	0.190	0.559	0.036	0.014	39%	1.666	51.243
		High	25	0.243	0.502	0.047	0.016	34%	1.612	64.210

Source: data processing results, 2025

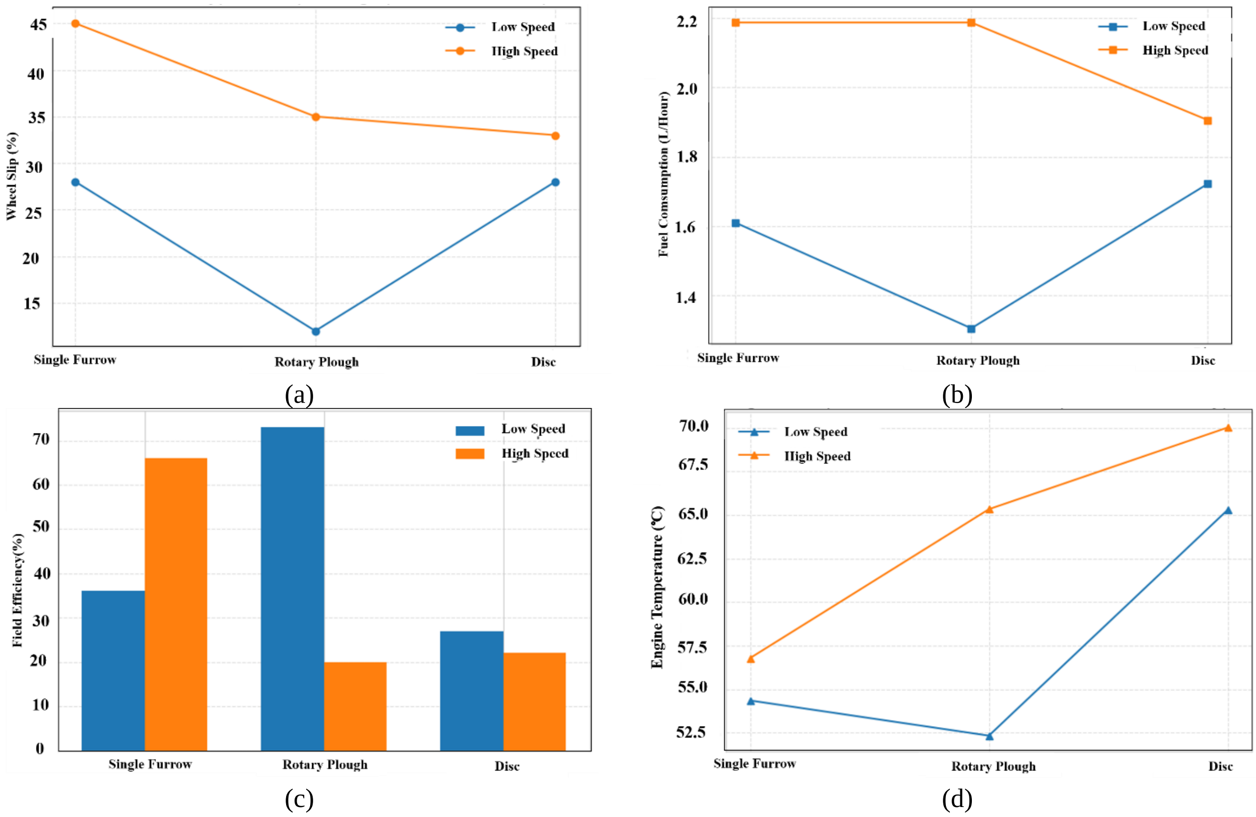

Fig. 4. Performance test results of mini hand tractor: (a) Wheel Slip (%), (b) Fuel Consumption (L h^{-1}), (c) Average Field Efficiency, and (d) Average Engine Temperature (°C) for different plough types at two speeds

The data given in Figure 4a indicate that the Single Furrow Plough resulted in the highest wheel slip, averaging above 30% at high operating speed. This result suggests that the plough requires a substantial draft force, causing considerable traction loss in the tractor. In contrast, the Rotary Plough and Disc Plough exhibited lower and more stable wheel slip values, although the Disc Plough showed a slight increase at high speed. This trend reflects better traction management or lower draft power requirements under wet soil conditions. The working speed of a hand tractor in tilling soil does not always determine the optimal work efficiency, because too high a speed can cause excessive wheel slip (Adewoyin & Ajav, 2013). Hand tractor work efficiency is greatly influenced by work speed, implementation width, and wheel slip. High work speed can cause excessive wheel slip, thus reducing work capacity and increasing fuel consumption (Moitzi *et al.*, 2014). Implementation with a width that matches the wheel width can increase work capacity and reduce wheel slip. Low wheel slip can increase work efficiency and save fuel (Ivanov, Fedorenko, Tarkivsky, & Petukhov, 2021; Karparvarfard & Rahmanian-Koushkaki, 2015; Pedersen & Lind, 2017; Soylu & Çarman, 2020; Šumanovac *et al.*, 2021).

Wheel slip in Figure 4a is a phenomenon that occurs when the forward speed of the hand tractor decreases due to operational load on field conditions. This means that the wheel rotates repeatedly at one point in the land without moving the tractor forward (Idkham, Dhafir, & Putri, 2021). Wheel slip can reduce the work efficiency of a tractor in tilling soil. Traction will increase with increasing wheel slip, but only up to a certain limit (Moeenifar, Kalantari, & Seyedi, 2013). According to Ivanov *et al.* (2021), the optimum slip of the tractor is in the range of 10-17%. The wheel slip on the tractor traction wheel can be measured from the comparison between the theoretical and actual speed of the tractor during operation with a load (Abrahám *et al.*, 2022). The test results show that the best wheel slip of the hand tractor is at low speed using the rotary plough at 12%. The documentation of wheel slip that occurred during field research can be seen in Figure 5.

(a) (b)

Fig. 5. Wheel Slip at (a) Low and (b) High speeds

Wheel slip can also affect the fuel consumption and emissions of a hand tractor, as higher wheel slip means higher engine power demand and lower fuel efficiency (de Melo, Tofoli, Daher, & Antunes, 2022; He *et al.*, 2022; Jensen, Antille, & Tullberg, 2025; Pedersen & Lind, 2017). Therefore, controlling wheel slip is important for reducing fuel cost and the environmental impact of soil tillage. Wheel slip can be influenced by various factors, such as soil type, soil moisture, soil compaction, tillage depth, tillage implement, tyre type, tyre pressure, ballast weight, and driving speed (Moitzi *et al.*, 2014). These factors can create spatial variability in soil resistance and traction, which can affect the performance and stability of the hand tractor. Wheel slip can be controlled by adjusting the working depth of the tillage implement according to the soil conditions and tractor performance. An automatic control system that can measure the wheel slip and adjust the tillage depth accordingly has been developed and tested in previous studies (de Melo *et al.*, 2022; Soylu & Çarman, 2020). The results showed that the automatic control system can reduce wheel slip and fuel consumption significantly compared to manual control by an operator.

Figure 4b explains that the hourly fuel consumption pattern showed a clear increase at high speed for all plough types, consistent with the higher engine workload. Both the Single Furrow Plough and Rotary Plough recorded the highest fuel consumption rates at high speed (approximately 2.1–2.2 L h^{-1}), corresponding to the high wheel slip in the Single Furrow Plough and the additional PTO power demand of the Rotary Plough. Nevertheless, this value should be normalised to L ha^{-1} (area-specific fuel consumption) to accurately assess the true economic efficiency of each plough type. Fuel consumption also reflected the mechanical load differences among plough types. The Rotary Plough required additional PTO power, while the Single Furrow Plough generated higher draft resistance, both contributing to greater fuel use. In contrast, the Disc Plough consumed less fuel, likely due to its lower soil engagement area. These findings are consistent with Jensen *et al.* (2025) and Md-Tahir *et al.* (2021), who emphasised that implement-soil interaction plays a major role in determining the overall energy efficiency of tillage machinery.

Fuel consumption of hand tractors is influenced by several factors, such as increased tractor power that requires greater combustion, different soil penetration resistance, and the size and load of a tractor (Tayel, Shaaban, & Mansour, 2015). To improve the quality of performance of two-wheel tractors, in addition to using alternative fuels, fuel efficiency can also be improved (Šumanovac *et al.*, 2021). This is important because a hand tractor that has been operating for a long time has low work efficiency. The economic life of agricultural machines such as combine harvester, transplanter and tractor is 5 years. After that, the machine's performance will decrease. The condition of the tractor will also affect the work capacity of tillage. A new tractor will have better performance than an old tractor.

Overall, the results indicate that the combination of moderate operating speed and rotary tillage mechanism provides the best balance between field efficiency, wheel slip, and fuel consumption. This insight can serve as a practical reference for farmers and machinery operators in wetland areas such as the Indonesian border region, where soil traction and power availability are critical factors affecting productivity.

The results of this study, as shown in Figure 4c, revealed that the field efficiency of the mini hand tractor varied significantly among plough types and operating speeds. The Rotary Plough achieved the highest field efficiency, particularly under the central tillage pattern, while the Single Furrow Plough and Disc Plough showed lower values. This difference can be attributed to the continuous soil pulverisation of the rotary blades, which reduces turning time and increases the effective working width. Similar results were reported by other researchers (Ding *et al.*, 2025; Rahman *et al.*, 2020; Zhang *et al.*, 2025), who found that continuous-action tillage implements improve operational efficiency under wet soil conditions. Higher operating speed tended to increase wheel slip, especially in the Single Furrow Plough, leading to a reduction in effective field capacity and an increase in fuel consumption. This pattern aligns with the findings of Galli (2024), who observed that excessive travel speed on soft soils results in traction losses and higher energy demand. Therefore, optimising tractor speed is essential to balance productivity and fuel economy in wetland operations.

Efficiency is one of the indicators and parameters of soil tillage and agricultural tool production success. The Rotary Plough achieved the highest field efficiency under the Central Pattern (average 46.5%), followed by the Single Furrow Plough operating with the Edge and Tight Patterns. The Spiral and Central Border Patterns tended to produce more variable and often lower efficiencies, indicating that tillage patterns minimising complex turning manoeuvres are generally the most time-efficient in field operations. Efficiency can be measured by comparing the time required to till a land with the area of land tilled (He *et al.*, 2022; Liu, Zhang, Wang, Chen, & Shen, 2013; Man *et al.*, 2020). High efficiency means that the time required to till a field is relatively short, while low efficiency means that the time required to till a field is relatively long. Efficiency can also be measured by comparing output and input, actual and expected results, or quality and quantity of output. Efficiency is influenced by various factors, such as soil conditions, type of tool or machine, operator skill, weather, and so on (Mishra, Mishra, & Santra, 2016). Therefore, it is important to conduct a comprehensive and objective analysis of efficiency in order to improve soil tillage performance and agricultural tool production. Effective field capacity is a measure of the average productivity of a tool or machine for soil tillage based on the total time required to complete the work (Olaoye & Rotimi, 2010; Ovchinnikov *et al.*, 2017).

Last, Figure 4d explains that Engine temperature serves as a direct indicator of thermal load and overall engine workload. The results show that the Disc Plough generated the highest average engine temperature, particularly at high speed (reaching approximately 64.8 °C), indicating sustained high load or reduced power transmission efficiency under these conditions. In general, higher operating speeds increased engine temperatures across all plough types. The Single Furrow Plough exhibited the lowest temperature range, possibly due to more effective engine cooling or fluctuating engine load, as evidenced by its high wheel slip values.

The combination of the obtained results shows that soil cultivation patterns have a significant impact on the performance of hand tractors in wetland conditions. The use of specific soil processing patterns can facilitate the hand tractor in achieving proper soil levelling and ensuring optimal soil quality for plant growth (Johansen, Haque, Bell, Thierfelder, & Esdaile, 2012). Effective processing patterns can enhance the appeal of hand tractors as agricultural aids in wetlands (Hobbs, 2021). The variation in hand tractor speeds also plays a crucial role in performance analysis. Research findings reveal that the appropriate speed can influence the efficiency of hand tractor work. Low speeds can result in suboptimal performance, while excessively high speeds can cause damage to crops and soil structure (Tabriz, Awal, Hossen, Ali, & Hossain, 2021). Therefore, determining the appropriate speed is a critical factor in improving the effectiveness of hand tractors in wetlands. Additionally, the selection of plough types is a significant factor in hand tractor performance. This study shows that choosing the right plough based on soil and crop conditions in wetlands is a crucial step in enhancing agricultural productivity. Suitable plough implement types can assist hand tractors in working more efficiently and producing better results (Lacour, Burgun, Perilhon, Descombes, & Doyen, 2014). This study has analysed the performance of hand tractors in wetland agriculture, considering soil processing patterns, speed variations, and plough types. The research findings reveal that these factors have a significant impact on the efficiency and productivity of hand tractors. Therefore, it is essential for farmers and agricultural practitioners to consider these factors when using hand tractors in wetland farming. Implementing improvement measures and optimising the working system of tractors appropriately can help enhance agricultural yields and contribute to better food security (Aybek, Kamer, & Arslan, 2010).

Conclusion

This study highlights the pivotal role of plough type, tillage pattern, and operating speed in determining the performance of mini hand tractors in wetland rice farming. The results confirm that rotary ploughs operating at low speeds within central tillage patterns significantly enhance field efficiency and reduce fuel consumption, while disc ploughs at high speeds under border patterns lead to excessive wheel slip and diminished performance. The proportional rise in engine temperature with speed further underscores the mechanical strain induced by suboptimal configurations. Overall, the findings emphasise that strategic selection and adjustment of tillage parameters can improve tractor efficiency by over 50%, reduce energy input, and promote sustainable mechanisation practices. These insights offer valuable guidance for farmers, engineers, and policymakers aiming to optimise resource use and operational stability in Southeast Asian wetland agriculture.

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Authors Contribution

Dwi Santoso: Investigating, Methodology, Writing-original draft, Conceptualization, Formal Analysis, Funding adquisition, Investigation, Supervision.

Deny Murdianto: Investigating, Methodology, Writing-original draft.

Ashish Malik: Review and editing services.

Saat Egra: Validation, Visualization, Writing- review, and editing

References

1. Abrahám, R., Majdan, R., Kollárová, K., Tkáč, Z., Hajdu, Š., Kubík, Ľ., & Masarovičová, S. (2022). Fatigue Analysis of Spike Segment of Special Tractor Wheels in Terms of Design Improvement for Chernozem Soil. *Agriculture*, *12*(4), 471. https://doi.org/10.3390/agriculture12040471
2. Adewoyin, A. O., & Ajav, E. A. (2013). Fuel consumption of some tractor models for ploughing operations in the sandy-loam soil of Nigeria at various speeds and ploughing depths. *Agricultural Engineering International: CIGR Journal*, *15*(3), 67-74.
3. Aybek, A., Kamer, H. A., & Arslan, S. (2010). Personal Noise Exposures of Operators of Agricultural tractors. *Applied Ergonomics*, *41*(2), 274-281. https://doi.org/10.1016/j.apergo.2009.07.006
4. Bhooshan, N., Raman, M. S., Gupta, S., Suyal, G., Singh, A., & Sharma, A. (2024). Revolutionizing agriculture: role of agricultural mechanization and global trends in farming technology. *Current Science*, *126*(10), 1209-1216. https://doi.org/10.18520/cs/v126/i10/1209-1216
5. Chartres, C. J., & Noble, A. (2015). Sustainable intensification: overcoming land and water constraints on food production. *Food Security*, *7*, 235-245. https://doi.org/10.1007/s12571-015-0425-1
6. Clark, M., & Tilman, D. (2017). Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. *Environmental Research Letters*, *12*(6), 64016. https://doi.org/10.1088/1748-9326/aa6cd5
7. Cole, M. B., Augustin, M. A., Robertson, M. J., & Manners, J. M. (2018). The science of food security. *Npj Science of Food*, *2*(1), 14. https://doi.org/10.1038/s41538-018-0021-9
8. Daum, T., Seidel, A., Awoke, B. G., & Birner, R. (2023). Animal traction, two-wheel tractors, or four-wheel tractors? A best-fit approach to guide farm mechanization in Africa. *Experimental Agriculture*, *59*, e12. https://doi.org/10.1017/S0014479723000091
9. de Melo, R. R., Tofoli, F. L., Daher, S., & Antunes, F. L. M. (2022). Wheel slip control applied to an electric tractor for improving tractive efficiency and reducing energy consumption. *Sensors*, *22*(12), 4527. https://doi.org/10.3390/s22124527
10. Ding, R., Qi, X., Chen, X., Mei, Y., & Li, A. (2025). The Current Development Status of Agricultural Machinery Chassis in Hilly and Mountainous Regions. *Applied Sciences*, *15*(13), 7505. https://doi.org/10.3390/app15137505
11. Evans, C. D., Morrison, R., Cumming, A., Bodo, A., Burden, A., Callaghan, N., Clilverd, H., Cooper, H., Cowan, N., & Crabtree, D. (2023). *Defra Lowland Peat 2: Managing agricultural systems on lowland peat for decreased greenhouse gas emissions whilst maintaining agricultural productivity. Report to Defra for Project SP1218*.
12. Galli, L. E. (2024). *Sustainability of agricultural tractors usage in open field and in specialized crops, from the performance and environmental standpoints*.
13. Gamage, A., Gangahagedara, R., Gamage, J., Jayasinghe, N., Kodikara, N., Suraweera, P., &

Merah, O. (2023). Role of organic farming for achieving sustainability in agriculture. *Farming System*, *1*(1), 100005. https://doi.org/10.1016/j.farsys.2023.100005

14. He, C., Wang, Y.-Q., Yu, W.-B., Kou, Y.-H., Yves, B. N., Zhao, X., & Zhang, H.-L. (2022). Comprehensive analysis of resource utilization efficiency under different tillage systems in North China Plain. *Journal of Cleaner Production*, *347*, 131289. https://doi.org/10.1016/j.jclepro.2022.131289
15. Herranz-Matey, I. (2025). Analyzing tractor productivity and efficiency evolution: A methodological and parametric assessment of the impact of variations in propulsion system design. *Agriculture*, *15*(15), 1577. https://doi.org/10.3390/agriculture15151577
16. Hobbs, P. R. (2021). Tillage and crop establishment in South Asian rice-wheat systems: Present practices and future options. In *The Rice-Wheat Cropping System of South Asia* (pp. 1–22). CRC Press. https://doi.org/10.1201/9781003210658-1
17. Idkham, M., Dhafir, M., & Putri, L. (2021). Functional and performance test of modified lug wheel on two wheels tractor with pivot type trailer. *IOP Conference Series: Earth and Environmental Science*, *922*(1), 12016.
18. Iram, S., Iqbal, A., Ahmad, K. S., & Jaffri, S. B. (2020). Congruously designed eco-curative integrated farming model designing and employment for sustainable encompassments. *Environmental Science and Pollution Research*, *27*(16), 19543-19560. https://doi.org/10.1007/s11356-020-08499-5
19. Ivanov, A. B., Fedorenko, V. F., Tarkivsky, V. E., & Petukhov, D. A. (2021). Rational use of energy potential and reduction of the negative impact on the soil of agricultural tractor propellers using instrumental control of slipping. *IOP Conference Series: Earth and Environmental Science*, *808*(1), 12019. https://doi.org/10.1088/1755-1315/808/1/012019
20. Jensen, T. A., Antille, D. L., & Tullberg, J. N. (2025). Improving on-farm energy use efficiency by optimizing machinery operations and management: A review. *Agricultural Research*, *14*(1), 15-33. https://doi.org/10.1007/s40003-024-00824-5
21. Johansen, C., Haque, M. E., Bell, R. W., Thierfelder, C., & Esdaile, R. J. (2012). Conservation agriculture for small holder rainfed farming: Opportunities and constraints of new mechanized seeding systems. *Field Crops Research*, *132*, 18-32. https://doi.org/10.1016/j.fcr.2011.11.026
22. Karparvarfard, S. H., & Rahmanian-Koushkaki, H. (2015). Development of a fuel consumption equation: Test case for a tractor chisel-ploughing in a clay loam soil. *Biosystems Engineering*, *130*, 23-33. https://doi.org/10.1016/j.biosystemseng.2014.11.015
23. Khodabakhshi, A., Kalantari, D., & Mousavi, S. R. (2013). Effect of design parameters of rotary tillers on unevenness of the bottom of the furrows.
24. Lacour, S., Burgun, C., Perilhon, C., Descombes, G., & Doyen, V. (2014). A model to assess tractor operational efficiency from bench test data. *Journal of Terramechanics*, *54*, 1-18. https://doi.org/10.1016/j.jterra.2014.04.001
25. Liu, Q., Yu, R., Suo, H., Cai, Y., Chen, L., & Jiang, H. (2025). Autonomous Driving in Agricultural Machinery: Advancing the Frontier of Precision Agriculture. *Actuators*, *14*(9), 464. https://doi.org/10.3390/act14090464
26. Liu, R., Zhang, P., Wang, X., Chen, Y., & Shen, Z. (2013). Assessment of effects of best management practices on agricultural non-point source pollution in Xiangxi River watershed. *Agricultural Water Management*, *117*, 9-18. https://doi.org/10.1016/j.agwat.2012.10.018
27. Man, Z., Yuhan, J. I., Shichao, L. I., Ruyue, C. A. O., Hongzhen, X. U., & Zhenqian, Z. (2020). Research progress of agricultural machinery navigation technology. *Nongye Jixie Xuebao/Transactions of the Chinese Society of Agricultural Machinery*, *51*(4).
28. Marambanyika, T. (2015). *An analysis of the impacts of human activities and management strategies on wetland processes in southern Zimbabwe*. University of KwaZulu-Natal, Pietermaritzburg.

29. Md-Tahir, H., Zhang, J., Xia, J., Zhou, Y., Zhou, H., Du, J., Sultan, M., & Mamona, H. (2021). Experimental investigation of traction power transfer indices of farm-tractors for efficient energy utilization in soil tillage and cultivation operations. *Agronomy*, *11*(1), 168. https://doi.org/10.3390/agronomy11010168
30. Mishra, S., Mishra, D., & Santra, G. H. (2016). Applications of machine learning techniques in agricultural crop production: a review paper. *Indian Journal of Science and Technology*, *9*(38), 1–14. https://doi.org/10.17485/ijst/2016/v9i38/95032
31. Moeenifar, A. M., Kalantari, D., & Seyedi, S. R. M. (2013). Application of dimensional analysis in determination of traction force acting on a narrowblade. *International Journal of Agriculture and Crop Sciences*, *5*(9), 1034.
32. Moitzi, G., Wagentristl, H., Refenner, K., Weingartmann, H., Piringer, G., Boxberger, J., & Gronauer, A. (2014). Effects of working depth and wheel slip on fuel consumption of selected tillage implements. *Agricultural Engineering International: CIGR Journal*, *16*(1), 182-190.
33. Olaoye, J. O., & Rotimi, A. O. (2010). Measurement of agricultural mechanization index and analysis of agricultural productivity of farm settlements in Southwest Nigeria. *Agricultural Engineering International: CIGR Journal*, *12*(1).
34. Ovchinnikov, A. S., Mezhevova, A. S., Novikov, A. E., Fomin, S. D., Pleskachev, Y. N., Borisenko, I. B., Zvolinsky, V. P., Tyutyuma, N. V, & Vorontsova, E. S. (2017). Energy and agrotechnical indicators in the testing of machine-tractor units with subsoiler. *ARPN Journal of Engineering and Applied Sciences*, *12*(24), 7150-7160.
35. Pawlak, K., & Kołodziejczak, M. (2020). The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability*, *12*(13), 5488. https://doi.org/10.3390/su12135488
36. Pedersen, S. M., & Lind, K. M. (2017). Precision agriculture–from mapping to site-specific application. *Precision Agriculture: Technology and Economic Perspectives*, 1-20. https://doi.org/10.1007/978-3-319-68715-5_1
37. Rahman, M. E., Bin Halmi, M. I. E., Bin Abd Samad, M. Y., Uddin, M. K., Mahmud, K., Abd Shukor, M. Y., Sheikh Abdullah, S. R., & Shamsuzzaman, S. M. (2020). Design, operation and optimization of constructed wetland for removal of pollutant. *International Journal of Environmental Research and Public Health*, *17*(22), 8339. https://doi.org/10.3390/ijerph17228339
38. Salam, R. H., Fikry, M. Y., & Rizali, M. (2024). Two-Wheel Tractor Performance Test With Variations Of Soil Trilling Patterns In Rice Land, East Lombok. *Ecobios Journal Of Environmental Science*, *1*(1), 11-18. https://doi.org/10.71024/ecobios/2024/v1i1/8
39. Santoso, D., Murdianto, D., Egra, S., Wahyuni, E., Murtilaksono, A., Tahcfulloh, S., & Sulistyo, A. (2025). Bibliometric analysis of oil palm pre-harvest machinery. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *29*(5), e287540. https://doi.org/10.1590/1807-1929/agriambi.v29n5e287540
40. Shah, F., & Wu, W. (2019). Soil and crop management strategies to ensure higher crop productivity within sustainable environments. *Sustainability*, *11*(5), 1485. https://doi.org/10.3390/su11051485
41. Singh, C., & Nath, R. (2020). *Farming system and sustainable agriculture: Agricultural reform*. Sgoc Publication.
42. Slater, A. (2021). *Fossil Fuels, Fossil Waters: Aquifers, Pipelines, and Indigenous Water Rights*. Saturation. An Elemental Politics. Durham/London: Duke University Press. https://doi.org/10.1215/9781478013044-004
43. Soylu, S., & Çarman, K. (2020). Automatic Control of Wheel Slip in Soil Tillage. *Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi*, *9*(2), 848-858. https://doi.org/10.28948/ngumuh.722088

44. Šumanovac, L., Jug, D., Jug, I., Japundžić-Palenkić, B., Mirosavljević, K., Popijač, M., & Benković-Lačić, T. (2021). Influence of aggregated tillage implements on fuel consumption and wheel slippage. *Tehnički Vjesnik*, *28*(3), 956-962. https://doi.org/10.17559/TV-20201130162613
45. Tabriz, S. S., Awal, M. A., Hossen, M. S., Ali, M. R., & Hossain, M. A. (2021). *Development and Performance Evaluation of a Two-Wheel Tractor Mounted Conservation Tillage Trencher for Sugarcane*. https://doi.org/10.20944/preprints202107.0194.v1
46. Tahcfulloh, S., Wahyuni, E., Santoso, D., & Anam, A. S. (2024). Radiowave Pathloss Modeling Using Polynomial Methods for Wet and Dry Land Adan Rice Agriculture. *2024 11th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, 379-384. https://doi.org/10.1109/EECSI63442.2024.10776287
47. Tayel, M. Y., Shaaban, S. M., & Mansour, H. A. (2015). Effect of plowing conditions on the tractor wheel slippage and fuel consumption in sandy soil. *International Journal of ChemTech Research*, *8*(12), 151-159.
48. Viana, C. M., Freire, D., Abrantes, P., Rocha, J., & Pereira, P. (2022). Agricultural land systems importance for supporting food security and sustainable development goals: A systematic review. *Science of the Total Environment*, *806*, 150718. https://doi.org/10.1016/j.scitotenv.2021.150718
49. Wahyuni, E., Sutrisno, A., Santoso, D., & Egra, S. (2023). *Smallholding farmers wellbeing in ecosystem services area of high food provider in border area of Indonesia.* https://doi.org/10.31328/jsed.v6i2.4838
50. Zhang, C., Li, J., Li, C., Lin, P., Shi, L., & Xiao, B. (2025). Electrification and Smartification for Modern Tractors: A Review of Algorithms and Techniques. *Agriculture*, *15*(18), 1943. https://doi.org/10.3390/agriculture15181943

مقاله کوتاه

بررسی تاثیر الگوهای شخم‌زنی، سرعت عملیات و انواع شخم بر عملکرد تراکتورهای دستی کوچک در تالاب‌های مرزی

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چکیده

عملکرد تراکتورهای دستی کوچک برای بهبود بهره‌وری و کارایی عملیاتی برای تولید برنج تالابی بسیار مهم است. این مطالعه با هدف ارزیابی اثرات نوع شخم، الگوی شخم و سرعت عملیات بر عملکرد تراکتور دستی کوچک در منطقه مرزی تاراکان، اندونزی انجام شد. آزمایش‌های میدانی از سپتامبر ۲۰۲۴ تا ژانویه ۲۰۲۵ با استفاده از طرح فاکتوریل (۳×۵×۲) و تحلیل توصیفی کمی با SPSS Statistics 26 برای مقایسه عددی انجام شد. شاخص‌های عملکرد شامل لغزش چرخ (٪)، راندمان مزرعه (٪)، مصرف سوخت (لیتر در ساعت) و دمای موتور ($^{\circ}C$) هستند. نتایج نشان داد که شخم با گاوآهن دوار (تیلر) که تحت الگوی شخم از مرکز با سرعت کم (۱ متر بر ثانیه) کار می‌کرد، بالاترین راندمان مزرعه (۷۸٪) و کمترین مصرف سوخت (۱/۳۰۶ لیتر در ساعت) را به‌دست آورد. در مقابل، گاوآهن بشقابی با الگوی شخم از محیط در سرعت بالا (۲/۳ متر بر ثانیه) بیشترین لغزش چرخ (۴۸٪) و کمترین راندمان (۲۲٪) را ایجاد کرد که نشان‌دهنده افت قابل‌توجه عملکرد به دلیل درگیری بیش از حد خاک-چرخ است. دمای موتور متناسب با سرعت تراکتور افزایش یافت و در طول عملیات با سرعت بالا به ۷۰ درجه سانتی‌گراد رسید. این یافته‌ها نشان می‌دهند که بهینه‌سازی نوع شخم و انتخاب الگوی شخم می‌تواند راندمان تراکتور را تا ۵۶٪ افزایش دهد، مصرف سوخت را ۰/۸ لیتر در ساعت کاهش داده و پایداری عملیاتی را در شرایط تالاب بهبود بخشد. این مطالعه توصیه‌های عملی برای انتخاب و بهره‌برداری از تراکتورهای دستی کوچک برای افزایش بهره‌وری انرژی و پایداری در سیستم‌های مکانیزاسیون تالاب در مناطق مرزی جنوب شرقی آسیا ارائه می‌دهد.

واژه‌های کلیدی: ارزیابی عملکرد، تالاب‌ها، تراکتور دستی کوچک، سیستم خاکورزی، منطقه مرزی

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