

Integration of Socio-Agroecosystem in the Implementation of Semi-Autonomous Hand Tractors in Wetlands: Efforts to Empower Women and the Elderly Towards Sustainable Agriculture

Dellah Tian Saputri¹, Amin Rejo^{2*}, Rizky Tirta Adhiguna²

¹Master's Study Program in Agricultural Industrial Technology, Faculty of Agriculture, Sriwijaya University, Palembang, Indonesia

²Agricultural Engineering Study Program, Department of Agricultural Technology, Faculty of Agriculture, Sriwijaya University, Ogan Ilir, Indonesia

*Corresponding Author: aminrejo@unsri.ac.id

Article history

Received	Received in revised form	Accepted	Available online
01 November 2025	16 December 2025	16 December 2025	21 December 2025

Abstract: Pelabuhan Dalam Village in Ogan Ilir Regency represents a swamp–lowland agricultural ecosystem increasingly challenged by labor shortages, soil degradation from conventional tillage, and limited participation of women and elderly farmers. This study integrates a socio-agroecosystem approach with the adoption of a semi-autonomous hand tractor to improve technical performance and strengthen social inclusion. A mixed-methods design was applied, combining field experiments, soil measurements, structured surveys, and in-depth interviews with 30 respondents (20 women and 10 elderly farmers). Quantitative analysis using paired t-tests showed improvements in tillage time (8.5 to 5.2 h/ha), fuel consumption (12.5 to 9.1 L/ha), and work efficiency (61.2% to 84.8%). Soil compaction decreased by 21.9%, accompanied by increases in moisture content, pH, and organic matter. Social participation of women and elderly farmers increased substantially in operator training and group management. Economically, farmers' net income increased from IDR 1,450,000/ha to IDR 6,350,000/ha. These findings indicate that socio-agroecosystem integration through semi-autonomous mechanization can enhance technical efficiency, social inclusion, and environmental sustainability. Further longitudinal studies are recommended to confirm long-term ecosystem and livelihood outcomes.

Keywords: socio-agroecosystem, semi-autonomous tractor, women farmers, elderly farmers, soil compaction.

1. Introduction

Agriculture in Indonesia, particularly in South Sumatra, plays a vital role in supporting food security and the rural economy [1]. One of the most potential agricultural areas is Pelabuhan Dalam Village, Pemulutan District, Ogan Ilir Regency, which is dominated by a swamp–lebak agroecosystem [2]. The land conditions, characterized by seasonal flooding and dependence on tidal water, create unique technical and social challenges in farm management [3]. With a population of approximately 2,816 and an area of ± 7.71 km², most residents depend on rice cultivation as their primary livelihood. However, limited productive labor and high land preparation costs reduce overall farming efficiency [4].

Labor migration among the younger population to urban industries has led to a decline in active farmers, leaving agricultural activities largely managed by women and elderly groups [5]. Although these groups contribute significantly to rural livelihoods, their role in land preparation and mechanization remains limited due to physical constraints and lack of access to training or user-friendly technology [6]. Empowering women and elderly farmers are therefore essential to strengthen community resilience and achieve inclusive

agricultural productivity [7].

In addition to social challenges, conventional tractor uses without controlled path planning often causes soil compaction, leading to reduced porosity and permeability that inhibit root growth and decrease land productivity [8]. Reported that repeated soil compaction in swamp rice fields could reduce yields by up to 15% per planting season [9]. Thus, there is an urgent need for more efficient, precise, and eco-friendly mechanization technologies to sustain swamp agroecosystems [10].

The socio-agroecosystem approach integrates social, economic, and ecological interactions within agricultural systems [11]. This concept emphasizes local participation, equitable access to technology, and natural resource preservation. In the context of Pelabuhan Dalam Village, the socio-agroecosystem framework can be implemented through environmentally friendly semi-autonomous hand tractors that are easier to operate, even by women and elderly farmers [12]. This technology uses GPS-based navigation and sensors to control direction, speed, and plowing depth automatically, reducing operator fatigue and avoiding overlapping passes [13].

This study was conducted to address the need for sustainable and inclusive wetland agriculture. Specifically, it aims to: (1) identify the socio-economic characteristics of farmers in Pelabuhan Dalam Village; (2) analyze the technical performance of semi-autonomous hand tractors compared with conventional ones in terms of efficiency and soil impact; (3) assess social and economic changes among women and elderly groups after the adoption of technology; and (4) formulate a socio-agroecosystem-based strategy as a community-driven model for sustainable agriculture [14]. Through technology integration and social empowerment, Pelabuhan Dalam is expected to become a practical example of equitable and sustainable modern agriculture in Indonesia's wetland regions.

2. Material and Methods

2.1. Material

The study utilized a prototype semi-autonomous hand tractor equipped with GPS-based navigation, ultrasonic sensors for obstacle detection, and a microcontroller for path control and plowing depth regulation. A conventional 8.5 HP hand tractor served as the comparison. Supporting instruments included a digital penetrometer (kN/m^2), soil moisture meter, pH meter, and observation sheets for recording fuel use, working time, and overlap percentage. Structured questionnaires and in-depth interview guides were used to capture social and economic dimensions.

2.2. Research Design and Approach

A mixed-methods approach was employed, integrating quantitative measurements of soil and tractor performance with qualitative assessments of social and economic changes. The quantitative component evaluated efficiency, soil conditions, and economic indicators before and after semi-autonomous tractor implementation. The qualitative component used interviews and thematic coding to analyze community participation, empowerment, and technology acceptance within a socio-agroecosystem framework.

A mixed-methods research design was employed to capture the multidimensional nature of socio-agroecosystem integration. Quantitative components included field measurements before and after the implementation of the semi-autonomous tractor. Qualitative data were collected through semi-structured interviews and focus group discussions to elicit insights from women farmers and elderly participants on their experiences, acceptance, and perceived benefits of the technology.

Additional supporting instruments included a calibrated digital penetrometer for measuring soil compaction, a soil moisture probe, a portable pH meter, and laboratory equipment for organic matter analysis

using the Walkley–Black method. Data on fuel consumption, field capacity, effective working time, and overlap percentage were systematically recorded for quantitative analysis.

2.3. Sampling Method and Respondents

A purposive sampling technique was used to ensure the inclusion of farmers directly involved in wetland rice cultivation and with prior exposure to mechanization activities. This method was selected to capture the perspectives of groups most affected by labor shortages and technological change. A total of 30 respondents (20 women and 10 elderly farmers) participated. This sample size meets the minimum recommended threshold for paired comparisons and qualitative saturation in smallholder farming studies. It was also determined based on the population size of active wetland farmers in Pelabuhan Dalam Village and logistical feasibility within one planting season.

Respondent Distribution

- a. Women farmers: 20
- b. Elderly farmers (>55 years): 10

This distribution aligns with the demographic characteristics of local agricultural labor availability.

2.4. Stage Technical Measurement Procedures

2.4.1 Soil Compaction Measurement

Soil compaction was measured using a digital penetrometer following standard wetland soil procedures:

- a. Measurement depth: 0–30 cm
- b. Depth intervals: Every 10 cm
- c. Number of sampling points: 5 points per plot
- d. Replication: 3 replications before and after tractor treatment
- e. Units: kN/m^2

Averaged compaction values were used in the analysis.

2.4.2 Soil Moisture, pH, and Organic Matter

Moisture: Measured using a digital soil moisture meter at 10 cm depth, 5 points \times 3 replications. pH: Measured with a portable pH meter using a 1:2.5 soil-water suspension. Organic Matter: Determined using the Walkley–Black method on composite samples collected from 5 subsampling points. All measurements were conducted under similar field conditions before and after tractor implementation to ensure comparability.

2.4.3. Qualitative Data Collection and Analysis

Qualitative data were obtained through Semi-structured interviews; Focus group discussions with women and elderly farmers; Observations of training activities and machine operation; and Documentation (photos/videos).

Data were analyzed using Miles & Huberman's approach:

- a. Data condensation
- b. Coding and categorization of emerging themes

c. Pattern interpretation

Triangulation used interview transcripts, field notes, and documentation to increase validity.

3. Results and Discussion

This study was conducted in Pelabuhan Dalam Village with 30 respondents (20 women and 10 elderly farmers). Data were obtained through field measurements, observations, interviews, and economic analysis.

3.1. Technical Efficiency of Semi-Autonomous Tractors

The semi-autonomous hand tractor demonstrated notable improvements in technical performance compared to the conventional system. Tillage time decreased from 8.5 to 5.2 hours/ha, fuel consumption from 12.5 to 9.1 L/ha, and overlap area from 18.4% to 8.4%. Consequently, work efficiency improved from 61.2% to 84.8%, representing a 23.6% relative increase.

Table 1. Technical performance before and after semi-autonomous tractor implementation

Parameter	Before	After
Land preparation time (hours/ha)	8.5	5.2
Fuel consumption (L/ha)	12.5	9.1
Overlap area (%)	18.4	8.4
Work efficiency (%)	61.2	84.8

These improvements reflect the benefits of automated steering and optimized path planning. Similar findings were reported by Susanti & Putra [15], who noted that navigation-based mechanization can increase energy efficiency by up to 30%. Although the paired t-test results show a consistent directional improvement, the magnitude of impact should be interpreted cautiously in the absence of complete variance and p-value data.

Interpretation of the technical results must consider the systemic nature of agricultural labor and resource use. Efficiency gains at the field level have broader implications for labor allocation, allowing women and elderly farmers to focus on complementary tasks such as seedbed preparation, seed selection, or fertilizer management. This redistribution of responsibilities supports a more balanced socio-agroecosystem. From a socio-agroecosystem perspective, improved technical efficiency reduces labor burden and creates opportunities for broader participation among women and elderly farmers, aligning with the principle of equitable technology access.



Figure 1. Manual hand tractor



Figure 2. Semi-Autonomous hand Tractors

3.2. Soil Physical and Ecological Improvements

Soil compaction decreased substantially from 178 to 139 kN/m², representing a 21.9% reduction. Soil moisture increased from 42.3% to 49.5%, soil pH improved from 5.4 to 5.8, and organic matter content rose from 2.1% to 2.9%.

Table 2. Soil physical conditions before and after semi-autonomous tractor use

Parameter	Before	After
Soil compaction (kN/m ²)	178.0	139.0
Soil moisture (%)	42.3	49.5
Soil pH	5.4	5.8
Organic matter (%)	2.1	2.9

Reduced soil compaction likely resulted from more controlled tractor movement, which minimizes repeated passes over the same area. This finding aligns with Purwanto et al. [16], who reported that excessive compaction in swamp rice fields can reduce yields by 10–15%. The improvement in soil moisture and pH suggests enhanced water retention and stabilization of soil chemical properties, supporting long-term wetland productivity. From an agroecosystem viewpoint, these ecological improvements contribute to maintaining soil resilience—an essential component of sustainable wetland farming systems.



Figure 3. Land used in research in the pelabuhan dalam village

3.3. Social Participation and Community Empowerment

The adoption of semi-autonomous tractors resulted in substantial increases in social participation across both women and elderly farming groups. Women’s participation rose from 28% to 65%, while elderly participation increased from 15% to 38%. Training involvement increased from 10% to 55%, and participation in farmer group management increased from 20% to 70%.

Table 3. Participation of women and elderly farmers before and after implementation

Category	Before (%)	After (%)
Women farmers	28	65
Elderly farmers	15	38
Training participants	10	55
Group management	20	70

These increases indicate not only improved accessibility of mechanization but also growing social inclusion. The semi-autonomous system reduces physical operating demands, enabling groups previously constrained by age or gender to participate more actively. Participation data reveal transformative shifts among women and elderly farmers. Increased involvement in training from 10% to 55% suggests that semi-autonomous technologies reduce psychological and physical barriers to learning. For elderly farmers, the simplified operating system reduces the fear of operating machinery and promotes continued participation in agricultural activities.

Similarly, the increase in group management participation underscores a growing sense of ownership and leadership within the community. These social dynamics are essential for sustaining mechanization programs, as local committees often manage scheduling, maintenance, and cost-sharing for shared farm equipment.

Digital and semi-autonomous technologies can expand opportunities for marginalized groups when designed to be user-friendly and safe. From a socio-agroecosystem standpoint, increased participation strengthens community capital, improves knowledge flow, and enhances collective capacity for sustainable

agriculture.

3.4 Economic Impacts

Economic analysis reveals notable improvements in farm profitability. Production costs decreased from IDR 5,750,000/ha to IDR 4,900,000/ha, while income increased from IDR 7,200,000/ha to IDR 11,250,000/ha. Net profit rose from IDR 1,450,000/ha to IDR 6,350,000/ha, and the B/C ratio increased from 1.25 to 2.29.

Table 4. Economic analysis before and after technology implementation

Parameter	Before (Rp/ha)	After (Rp/ha)
Production cost	5,750,000	4,900,000
Income	7,200,000	11,250,000
Net profit	1,450,000	6,350,000
B/C ratio	1.25	2.29

The increase in profits is largely attributed to reduced tillage time, lower fuel consumption, and improved soil performance. The income increase of nearly fivefold aligns with Purnomo et al. [17] and Tulungen [18], who reported that community-based mechanization can increase farmers’ returns by more than 50%. The notable increase in net income, from IDR 1.45 million to IDR 6.35 million per hectare, highlights the economic relevance of the technology. Beyond cost reductions, farmer testimonies indicate that improved soil conditions contributed to better plant vigor and higher panicle density. Although the study did not directly measure yield, these observations suggest a positive correlation between soil health and crop performance.

Economic resilience is further strengthened by reduced machine repair frequency, enabled by minimized steering errors and smoother navigation. These indirect savings reinforce farmers’ perception that semi-autonomous mechanization is both beneficial and economically viable. While these results are promising, economic stability should be assessed across multiple seasons to capture variability in input prices, labor conditions, and yield fluctuations.

3.5 Integration of the Socio-Agroecosystem Framework

The findings demonstrate the interconnectedness of technical, ecological, social, and economic dimensions. The semi-autonomous tractor serves not only as a mechanization tool but also as:

- A social enabler — encouraging participation beyond traditionally dominant groups.
- An ecological stabilizer — reducing soil stress and improving fertility indicators.
- An economic catalyst — lowering costs and enhancing profitability.

These outcomes support the core principles of socio-agroecosystems: technological innovation must reinforce social inclusion and ecological sustainability

[19]. However, long-term assessment is required to validate sustained benefits. Future studies should examine seasonal variability, impacts on yield, and community-level institutional changes. The interconnected improvements across technical, ecological, social, and economic dimensions illustrate the systemic potential of semi-autonomous mechanization. The technology acts as a catalyst, amplifying social inclusion, ecological stewardship, and production efficiency. However, successful integration requires ongoing community engagement, maintenance training, and adaptive management to ensure long-term sustainability.

3.6 Operator Fatigue and Workload Assessment

Beyond efficiency metrics, operator fatigue was evaluated through self-reported indicators of physical strain, such as back pain, wrist tension, and overall exhaustion after fieldwork. Respondents reported a 47% reduction in perceived fatigue after using the semi-autonomous tractor. Women farmers, in particular, noted that they could complete land preparation tasks without assistance from male family members, demonstrating a significant shift in the division of labor.

The reduced need for continuous manual steering and force exertion allowed elderly farmers to operate machinery that they previously avoided due to safety concerns. This change suggests that semi-autonomous systems not only improve productivity but also prolong the active farming years of aging populations.

3.7 Field Capacity and Tillage Uniformity

Field capacity, measured as the effective area completed per hour, increased by 29%. Interviews suggested that the improved uniformity of tillage resulted in more consistent seedling establishment during subsequent planting. Farmers noted fewer patches of uneven soil depth, which typically lead to waterlogging or poor germination. These observations indicate that semi-autonomous machines not only work faster but also create more favourable agronomic conditions.

3.8 Community Perceptions of Safety

Safety perception improved substantially among all respondent groups. The automatic obstacle detection system was particularly valued because it minimized the fear of collisions or sudden directional errors. Women farmers expressed that this feature made them feel “more confident and more secure” when operating in muddy fields with limited visibility.

4. Conclusion

The integration of a socio-agroecosystem approach with the use of a semi-autonomous hand tractor in Pelabuhan Dalam Village generated positive technical, ecological, social, and economic outcomes.

The semi-autonomous system improved operational efficiency by reducing tillage time, fuel consumption, and overlap, resulting in higher work efficiency compared to conventional methods. Soil conditions also improved, as reflected by reduced compaction and increases in moisture, pH, and organic matter, indicating better soil structure for wetland rice cultivation. Socially, the technology enabled greater participation of women and elderly farmers, who were previously limited by physical constraints, demonstrating improved inclusiveness in agricultural activities and decision-making processes. Economically, the reduction in production costs and the increase in farm income contributed to higher profitability for smallholder farmers. Overall, the findings suggest that semi-autonomous mechanization, when embedded within a socio-agroecosystem framework, can support more efficient and inclusive wetland agriculture. However, further multi-season studies are recommended to assess long-term sustainability, economic variability, and broader institutional impacts across different wetland contexts.

References

- [1] C. Mendoza *et al.*, “Precision farming and semi-autonomous tractor systems in wetland agriculture,” *J. Agric. Eng.*, vol. 45, no. 3, pp. 215–230, 2020.
- [2] L. Prause, “Digital agriculture and labor: A few challenges for social sustainability,” *Sustainability*, vol. 13, no. 11, 2021, Art. no. 5980.
- [3] A. R. Dhar, M. M. Islam, A. Jannat, and J. U. Ahmed, “Wetland agribusiness aspects and potential in Bangladesh,” *Data Brief*, vol. 16, pp. 617–621, 2018.
- [4] S. E. Mohamed, A. A. Belal, S. K. Abd-Elmabod, M. A. El-Shirbeny, A. Gad, and M. B. Zahran, “Smart farming for improving agricultural management,” 2023.
- [5] FAO, *Empowering Women in Agriculture: Technology and Inclusion Strategies*. Food and Agriculture Organization of the United Nations, 2022.
- [6] H. Purwanto *et al.*, “Impact of soil compaction on swamp rice productivity,” *J. Soil Environ.*, vol. 24, no. 2, pp. 77–88, 2022.
- [7] L. Jiang, B. Xu, N. Husnain, and Q. Wang, “Overview of agricultural machinery automation technology for sustainable agriculture,” *Agronomy*, vol. 15, no. 6, 2025, Art. no. 1471, doi: 10.3390/agronomy15061471.
- [8] Y. He, H. Jiang, H. Fang, Y. Wang, and Y. Liu, “Research progress of intelligent obstacle detection methods of vehicles and their application on agriculture,” *Trans. Chin. Soc. Agric. Eng.*, vol. 34, no. 21, pp. 21–32, 2018.
- [9] M. Padhiary, D. Saha, R. Kumar, L. N. Sethi, and A. Kumar, “Enhancing precision agriculture: A

- comprehensive review of machine learning and AI vision applications in all-terrain vehicle for farm automation,” *Smart Agric. Technol.*, vol. 8, 2024, Art. no. 100483.
- [10] K. G. Liakos, P. Busato, D. Moshou, S. Pearson, and D. Bochtis, “Machine learning in agriculture: A review,” *Sensors*, vol. 18, no. 8, 2018, Art. no. 2674, doi: 10.3390/s18082674.
- [11] M. A. Altieri, *Agroecology: The Science of Sustainable Agriculture*. CRC Press, 2021.
- [12] F. J. Dessart, J. Barreiro-Hurlé, and R. van Bavel, “Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review,” *Eur. Rev. Agric. Econ.*, vol. 46, no. 3, pp. 417–471, 2019.
- [13] D. Durant, A. Farruggia, and A. Trichieur, “Utilization of common reed (*Phragmites australis*) as bedding for housed suckler cows: Practical and economic aspects for farmers,” *Resources*, vol. 9, no. 12, 2020.
- [14] L. Susanti and R. Putra, “Study of energy efficiency in semi-autonomous tractors based on navigation sensors,” *AgroTekno J.*, 2023.
- [15] K. A. Steen, P. Christiansen, H. Karstoft, and N. Jørgensen, “Using deep learning to challenge safety standard for highly autonomous machines in agriculture,” *J. Imaging*, vol. 2, no. 1, pp. 1–8, 2016.
- [16] F. R. Tulungen, “Precision agriculture technology to increase rice production efficiency in Indonesia,” *J. Cahaya Mandalika*, vol. 5, no. 2, pp. 720–727, 2024.
- [17] T. Purnomo, A. Santoso, and D. Wibowo, “Energy efficiency in mechanized paddy field operations,” *J. Indones. Agric. Technol.*, vol. 12, no. 1, pp. 34–45, 2021.
- [18] S. P. Sutisna, I. D. M. Subrata, and R. P. A. Setiawan, “Automatic steering control system for four-wheel tractor in straight path testing,” *Agritech*, vol. 35, no. 1, pp. 106–113, 2015.
- [19] C. Verdouw, B. Tekinerdogan, A. Beulens, and S. Wolfert, “Digital twins in smart farming,” *Agric. Syst.*, vol. 189, 2021, Art. no. 103046.