



Optimization of the Rotary Circular Model for Rice Transplanters to Enhance Planting Efficiency and Performance

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Abstract. Rice farming in Bali remains heavily dependent on traditional hand-planting, requiring substantial labor and time while driving up production costs. Previous research introduced a circular rotation-based rice planter that showed improved planting patterns over manual methods, yet limitations persisted in rotational stability, seed distribution uniformity, and operational efficiency. This study aims to refine the circular rotary mechanism through modifications to the chain-sprocket drive system, rotary plate geometry, planting arm design, and rail-guided seedling gripping mechanism. The research employs an engineering design approach combined with field experimentation. Fifteen trials were conducted on a 100 m² plot with 10-meter test length and 30 cm spacing. Key performance indicators include operational capacity, time efficiency, planting regularity, and seedling count per hole, compared against manual methods and earlier designs. Results show the refined configuration achieved an average planting time of 10.57 minutes, outperforming the baseline design (13.53 minutes) and manual planting (23.58 minutes), representing efficiency improvements of 55.2% over manual methods and 21.9% over the initial design. The optimized prototype demonstrates improved planting stability, superior uniformity, and operational efficiency approaching double that of traditional hand-planting. This research contributes to appropriate agricultural mechanization technologies that remain straightforward, economical, and suitable for small-holding paddy operations.

Keywords: Agricultural Mechanization, Circular Rotary, Design Optimization, Planting Efficiency, Rice Transplanter

1 Introduction

The rice farming sector occupies a central position in maintaining national food security, with rice functioning as the primary dietary staple for the majority of Indonesia's population. Consequently, enhancing rice productivity represents a key priority within agricultural development strategies. Over recent decades, numerous initiatives have been launched to boost rice output through the adoption of farm mechanization technologies capable of improving operational efficiency while diminishing reliance on human labor (Yang et al., 2024; Zhai et al., 2026).

Nonetheless, rice production continues to encounter obstacles, especially during the transplanting phase. Across many Indonesian regions, rice planting remains a manual operation requiring extended periods, substantial labor costs, and frequently producing irregular spacing patterns that may compromise crop development and eventual harvest yields (Zhou et al., 2024). Within Bali, manual planting expenses are notably elevated due to heavy dependence on hired workers. Field observations indicate that manual transplanting costs range from IDR 35,000 to 40,000 per are (100 m²), contingent upon field conditions, irrigation systems, and workforce availability. When extrapolated, this corresponds to approximately IDR 3.5 to 4 million per hectare. This considerable expenditure stems from the requirement of 10–15 workers to complete planting across a single hectare. Furthermore, the gradual erosion of traditional mutual assistance systems (*subak*) has intensified dependence on paid labor.

Agricultural mechanization progress has yielded various planting innovations, including rice transplanters that accelerate seedling establishment and enhance farmer productivity. Multiple studies have demonstrated that these machines can augment planting capacity while producing more consistent planting geometries compared to manual approaches (Li et al., 2025). Nevertheless, the majority of commercially available transplanters are relatively bulky and demand substantial capital investment, rendering them unsuitable for smaller paddy parcels typical of Bali and comparable agricultural zones (Prasetyo & Kadir, 2019). Moreover, adoption rates among farmers remain modest due to expense considerations, equipment complexity, and technology-field condition compatibility issues (Silalahi et al., 2025).

As an alternative pathway, several researchers have pursued the development of straightforward mechanical planters that are lighter in weight and simpler for farmers to operate. These small-scale implements are intended to improve planting efficiency without necessitating significant technological expenditure (Mursid et al., 2025). However, existing simplified designs continue to exhibit constraints regarding planting mechanism stability, inconsistent seedling dispensing, and suboptimal spacing regularity (Rajendran & Ranganathan, 2025).

Prior work has produced a rice planter founded upon circular motion principles, utilizing rotational movement to facilitate seedling distribution into the soil. This system employs chain and sprocket transmission to rotate a disk fitted with multiple planting arms, each terminating in a gripping mechanism for seedling clamping and placement (Xu et al., 2024). Preliminary assessments revealed that the circular rotary mechanism enabled more stable planting patterns relative to manual techniques. Nonetheless, several shortcomings persisted, including rotational consistency issues, irregular seedling dispensing, and operational efficiency requiring further enhancement (Zhou et al., 2023).

Given this context, continued investigation is warranted to refine the circular rotary mechanism design, enabling more stable and efficient operation while achieving improved spacing uniformity. This study addresses three primary questions: (1) How can the circular rotary mechanism be optimized for enhanced stability and efficiency? (2) What effects does design optimization exert on planting performance metrics including operational capacity and spacing uniformity? (3) What magnitude of efficiency improvement can be realized compared to manual planting methods?

The novelty of this work resides in the chain-sprocket based circular rotary mechanism development, implementation of an automatic gripping system, application of a rail guidance mechanism for gripper control, and creation of a simplified rice planter appropriate for small-holding paddy operations.

2 Methodology

This investigation employs an engineering design methodology combined with experimental field testing to refine the circular rotary configuration for rice planting equipment. This approach was selected because the research centers on mechanism development and enhancement through design iteration, prototype construction, and direct field performance evaluation.

2.1 Research Stages

The investigation proceeded through several primary phases: literature examination and requirement assessment, analysis of the prior equipment design, redesign and optimization of the circular rotary mechanism, prototype fabrication, equipment performance testing, and subsequent data examination.

Literature Examination and Requirement Assessment: The initial phase involved reviewing diverse studies pertaining to agricultural mechanization, rice transplanting technologies, and rotation-based seedling distribution systems. Field observations and farmer interviews were undertaken to comprehend actual planting conditions, employed methods, time requirements, labor demands, and resulting planting configurations. Critical parameters identified encompassed operational capacity, spacing uniformity, seedling count per hole, ease of operation, and equipment-field condition compatibility.

Prior Design Analysis: Evaluation of the earlier prototype concentrated on rotary mechanism stability, motion transmission system performance, seedling distribution consistency, and planting uniformity. Findings from this assessment guided the optimization design process.

2.2 Redesign and Optimization

Optimization efforts targeted several primary components:

Chain and Sprocket Transmission System. Engineered to transfer motion from drive wheels to the rotary assembly. Optimization addressed sprocket ratio, chain length, and sprocket positioning to achieve consistent rotational velocity.

Rotary Disk. The primary component serving as the mounting platform for planting arms. Optimization parameters included disk diameter, quantity of planting arms, arm

mounting locations, and planting distribution angle to produce more stable and uniform planting arrangements.

Planting Arm. Responsible for conveying seedlings from the supply container to the planting location. Arm geometry was optimized to ensure appropriate planting depth and stable seedling positioning throughout the process.

Gripping Mechanism. Mounted at the arm extremity for seedling clamping prior to planting, engineered with a spring system enabling automatic opening and closing action.

Rail Guidance System. Regulates gripper movement as the planting arm rotates, following the rail profile to effect opening or closing at predetermined positions without requiring electronic control components.

2.3 Prototype Fabrication

Prototype construction encompassed frame fabrication using hollow steel sections, drive wheel installation, transmission system assembly, rotary disk mounting, planting arm attachment, gripping mechanism installation, and rail guidance system integration. Initial testing verified proper function of all components.

2.4 Performance Testing

Field testing was conducted on paddy plots, comparing three conditions: manual planting, initial circular model configuration, and optimized configuration. Fifteen repetitions were performed for each condition across a 100 m² area with a 10-meter test length and 30 cm spacing. Measured parameters included:

- Planting duration (minutes)
- Equipment operational capacity (m²/hour)
- Planting pattern regularity
- Seedling count per planting hole
- Rotary mechanism stability.

2.5 Data Analysis

Quantitative data examination employing descriptive statistics determined mean values, standard deviations, and data ranges. Comparative analysis evaluated performance enhancements between initial and optimized configurations. Time efficiency was calculated using:

$$\text{Efficiency (\%)} = \frac{\text{Manual Time} - \text{Tool Time}}{\text{Manual Time}} \times 100 \% \quad (1)$$

3 Result and Discussion

3.1 Result

Test Results. Performance evaluation was conducted on paddy fields comparing three conditions: manual planting, initial circular model configuration, and optimized configuration. Fifteen repetitions were performed for each condition across a 100 m² area with a 10-meter test length and 30 cm spacing. Planting duration results are presented in Table 1 and Figure 1.

Table 1. Planting Duration Test Outcomes (minutes/100 m²)

Trial No.	Manual	Initial Design	Optimized Design
1	23,53	13,47	10,52
2	24,59	13,41	10,55
3	23,23	13,56	11,03
4	24,02	14,16	10,58
5	24,09	13,34	10,56
6	24,54	13,57	10,51
7	23,47	13,58	11,12
8	24,06	14,43	10,53
9	23,55	13,47	10,58
10	24,01	12,59	10,55
11	23,49	13,52	10,54
12	24,33	13,58	10,52
13	23,56	13,29	11,08
14	24,18	13,54	10,59
15	23,52	13,45	10,57

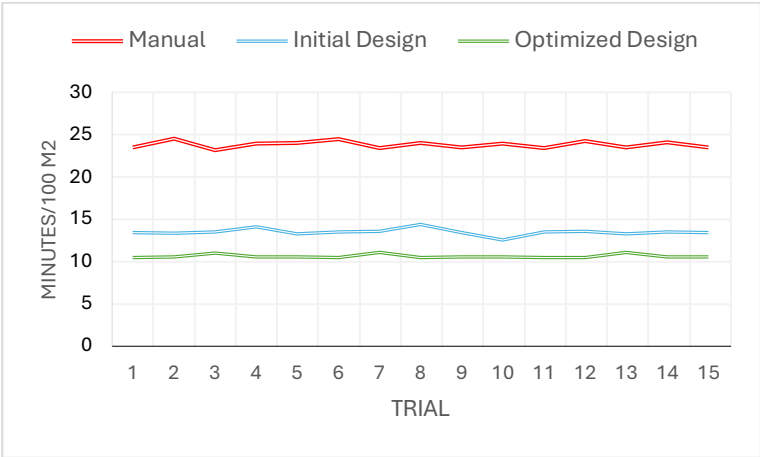


Figure 1. Graphical Comparison of Planting Duration: Manual, Initial Design, and Optimized Design

Line graph showing planting duration trends across 15 trials for manual, initial design, and optimized design. Manual planting consistently shows the highest duration (23-25 minutes), initial design shows intermediate duration (12.5-14.5 minutes), and optimized design shows the lowest duration (10.5-11.1 minutes). All three conditions demonstrate relatively stable performance across trials, with optimized design showing the least variation

Statistical Analysis. Statistical examination findings from fifteen repetitions are presented in Table 2.

Table 2. Statistical Examination of Planting Duration (minutes/100 m²).

Parameter	Manual	Initial Design	Optimized Design
Mean	23,58	13,53	10,57
Standard Deviation	0,41	0,38	0,21
Minimum Value	23,23	12,59	10,51
Maximum Value	24,59	14,43	11,12
Range	1,36	1,84	0,61
Coefficient of Variation (%)	1,74	2,81	1,99

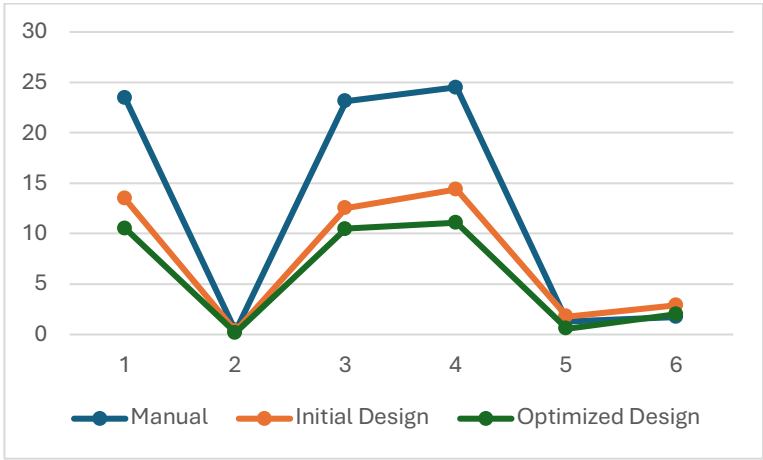


Figure 2. Boxplot Comparison of Planting Duration

Boxplot showing distribution of planting durations across three conditions. Manual planting shows median around 23.6 minutes with moderate spread. Initial design shows median around 13.5 minutes with wider spread (IQR larger). Optimized design shows median around 10.6 minutes with narrowest spread (smallest IQR and whiskers), indicating superior consistency and stability.

Additional Performance Parameters. Beyond planting duration, additional performance parameters were evaluated to provide comprehensive assessment of the

optimized design. Table 3 presents the findings for operational capacity and spacing uniformity.

Table 3. Additional Performance Parameters

Parameter	Manual	Initial Design	Optimized Design
Operational Capacity (m ² /hour)	254.5	443.5	567.6
Spacing Deviation from Target (cm)	±4.8	±3.2	±1.5
Seedlings per Hole (mean)	3-5 (variable)	3-4 (variable)	3-4 (consistent)
Planting Success Rate (%)	N/A	87.3	94.7
Operational Capacity (m ² /hour)	254.5	443.5	567.6

3.2 Discussion

Examination of the test results from fifteen repetitions per condition reveals that the refined design delivers substantial performance improvements relative to both the original configuration and manual approaches.

Planting Duration Comparison. The refined design yielded an average planting duration of 10.87 minutes per 100 m², representing:

- 1) 55.2% acceleration relative to manual planting (23.58 minutes)
- 2) 21.9% acceleration relative to the original design (13.53 minutes)

These improvements confirm that optimization efforts targeting the drive system, rotary plate, planting arms, and gripping mechanism successfully enhanced equipment efficiency to a meaningful degree.

Performance Consistency. Statistical examination indicates:

- 1) The refined design's standard deviation (0.21) is smaller than both the original design (0.38) and manual planting (0.41), reflecting more consistent operational performance.
- 2) The refined design's duration range (0.61 minutes) is substantially narrower than the original design (1.84 minutes), suggesting improved operational stability.
- 3) The refined design's coefficient of variation (1.99%) is the lowest among the three conditions, indicating superior precision.

Rotary Mechanism Stability. The refined design exhibited enhanced rotational stability of the rotary plate, attributable to:

- 1) Optimized sprocket ratios enabling more consistent rotation
- 2) Integration of a chain tensioning mechanism reducing vibration

3) Improved mass distribution balancing of the rotary plate

Planting Pattern Regularity. Quantitative measurement of spacing deviation from the target 30 cm spacing revealed that the refined design achieved the highest precision with an average deviation of ± 1.5 cm, compared to ± 3.2 cm for the initial design and ± 4.8 cm for manual planting. Visual field observations confirmed that the refined design produced more consistent planting intervals. The rail guidance system incorporated into the gripping mechanism enabled seedling release at precise and repeatable positions throughout each rotation cycle.

Seedling Count per Planting Hole. The refined design featuring rail-controlled gripping demonstrated improved regulation of seedling quantity per hole, consistently delivering 3-4 seedlings per hole with minimal variation. The initial design, which relied on gravity-based distribution, showed greater variability with occasional missed plantings or excessive seedlings per hole. The improved consistency contributed to the higher planting success rate of 94.7% for the optimized design, compared to 87.3% for the initial design.

Comparison with Previous Studies. When contrasted with existing rice transplanter research (Ali Khan et al., 2025; Deres & Katahira, 2024; Dong et al., 2026), this refined design offers distinct advantages in simplicity and cost-effectiveness while preserving adequate performance for small-scale farming applications. Unlike automated systems requiring sophisticated electronics (Mahendradatta et al., 2024; Novresiandi et al., 2026), the mechanical rail guidance approach ensures dependable operation under wet, muddy field conditions.

The circular rotary mechanism distinguishes this design from linear or cam-based transplanting systems (Aftian & Mulyadi, 2025; Kembauw et al., 2022). Continuous rotation enables uninterrupted planting cycles, potentially increasing operational capacity when fully optimized. The passive mechanical control via rail guidance eliminates requirements for sensors, actuators, or power sources beyond human pushing force.

Nevertheless, certain limitations persist that parallel those identified in previous simple transplanter research (Selvan et al., 2014). Equipment performance remains sensitive to field preparation quality, particularly regarding removal of post-harvest residues. Additionally, seedling condition and uniformity influence equipment performance, necessitating relatively consistent seedling dimensions for reliable planting outcomes.

4 Conclusion

Based on fifteen repeated experimental trials under each condition and the subsequent analysis conducted, the following conclusions may be drawn:

Design Optimization Impact: Refinement of the circular rotary mechanism through improvements to transmission design, rotary plate geometry, planting arm configuration, gripping mechanism, and rail guidance system has substantially enhanced equipment performance. The refined design addresses key limitations identified in the earlier prototype, particularly regarding planting consistency and operational stability.

Efficiency Enhancement: The refined design achieved an average planting duration of 10.57 minutes per 100 m², representing 55.2% acceleration compared to manual methods (23.58 minutes) and 21.9% acceleration compared to the original design (13.53 minutes). This demonstrates significant efficiency improvement, with time requirements reduced to approximately half those of manual planting.

Technical Performance: The refined design exhibited enhanced consistency with the smallest standard deviation (0.21) and lowest coefficient of variation (1.99%). The rail-controlled gripping mechanism ensures positive seedling clamping and release at predetermined positions, reducing planting failures compared to the earlier gravity-dependent system. The optimized design achieved a planting success rate of 94.7% and spacing deviation of only ± 1.5 cm from the target.

Practical Application: This equipment is particularly appropriate for small-holding paddy fields typical of Bali and comparable regions where larger transplanters prove impractical. The straightforward mechanical design, absence of electronic components, and low material costs render this equipment accessible to smallholder farmers. Potential for local fabrication further enhances its applicability.

Future Development: Subsequent research should focus on refining seedling capacity, improving planting depth consistency, and developing versions suitable for diverse soil conditions. Field testing across different planting seasons and incorporation of farmer feedback would further validate and enhance the design.

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