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Evaluation of direct seeded rice technology as a climate-smart approach for water saving, labour reduction and sustainable rice production in the Mullaiperiyar River Basin

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Abstract

Rice (*Oryza sativa* L.) cultivation in Tamil Nadu is increasingly constrained by water scarcity, labour shortages and climate variability, necessitating the adoption of resource-efficient and climate-resilient technologies. An On-Farm Trial (OFT) was conducted during Kharif 2023–2025 in the irrigated lowland ecosystems of the Mullaiperiyar River Basin, Theni district, Tamil Nadu, to evaluate the performance of Direct Paddy Seeder technology as an alternative to conventional rice establishment methods. The experiment was laid out in a Randomized Block Design with three treatments: Improved Direct Paddy Seeder (T₁), Broadcasting (T₂) and Conventional Transplanting (T₃), using rice variety CO 55. The results revealed that the Improved Direct Paddy Seeder significantly improved crop establishment, yield attributes and grain yield. The technology recorded the highest productive tillers m⁻² (1071), grains panicle⁻¹ (223.33) and grain yield (61.07 q ha⁻¹), registering yield advantages of 17.2 and 9.3 per cent over broadcasting and conventional transplanting, respectively. Mechanized direct seeding reduced seed requirement to 20 kg ha⁻¹, achieving seed savings of 75 per cent over broadcasting and 66.7 per cent over transplanting. Elimination of puddling, nursery raising and transplanting operations reduced irrigation water use by 33.3 per cent and enhanced water productivity to 6.96 kg ha⁻¹ mm⁻¹ compared with 4.36 kg ha⁻¹ mm⁻¹ under conventional transplanting. Labour requirement was reduced by 50.8 per cent through mechanized sowing and mechanical weed management, substantially lowering drudgery and dependence on scarce agricultural labour. Economic analysis indicated the highest net return (₹93,067 ha⁻¹) and benefit-cost ratio (3.25) under the Direct Paddy Seeder treatment. The study demonstrates that Direct Paddy Seeder technology is a scalable climate-smart intervention that conserves water, saves seed, reduces labour drudgery and enhances productivity and profitability. Its adoption can significantly strengthen the resilience and sustainability of rice-based farming systems in water-limited irrigated ecosystems.

Keywords: Climate-resilient agriculture, direct paddy Seeder, water conservation, labour-saving technology, water productivity, drudgery reduction, sustainable rice production, climate-smart agriculture

Introduction

Rice (*Oryza sativa* L.) is the staple food crop for more than half of the world population and plays a vital role in ensuring food and nutritional security in India. In Tamil Nadu, Rice is cultivated extensively under irrigated lowland ecosystems and contributes significantly to the state ag economy. The total rice cultivated area in Tamil Nadu is 21.58 lakh ha. Tamil Nadu alone contributes 4.21 percent in total rice production of India (Season and crop report, 2025). Conventional puddled transplanted rice (TPR) has been the dominant crop establishment method for decades; however, it is highly resource-intensive, requiring large quantities of irrigation water, labour, and energy inputs. Increasing water scarcity, rising labour costs, delayed monsoon onset, and climate variability have raised serious concerns regarding the sustainability of conventional rice production systems (Ramesh *et al.*, 2023 and Rao *et al.*, 2017) [2, 3].

The lowland rice ecosystems of Theni district are primarily supported by irrigation from the Mullaiperiyar and Sothuparai river basin systems. According to Agrisnet (2020), rice occupies about 8,930 ha in Theni district. The Mullaiperiyar irrigation network serves as the lifeline of

agriculture in the Cumbum Valley and adjoining command areas, while the Sothuparai reservoir supplements irrigation requirements in Periyakulam regions. Paddy cultivation in these command areas is highly dependent on timely water availability. However, irregular rainfall patterns, fluctuations in reservoir storage, increasing competition for water resources, and uncertainties in irrigation water release have intensified the need for water-saving rice production technologies.

Direct Seeded Rice (DSR) has emerged as a promising alternative to conventional transplanting. Unlike transplanted rice, DSR eliminates nursery raising, puddling, and transplanting operations, thereby reducing labour requirements and production costs (Farooq *et al.*, 2011; Mishra *et al.*, 2023) ^[5, 6]. Studies have reported that DSR can reduce irrigation water use by 15–35 per cent and labour requirements by 30–50 per cent while maintaining comparable or higher grain yields under suitable management practices (Ramesh *et al.*, 2023; Ghosh *et al.*, 2024) ^[2, 7]. Mechanization also helps address labour shortages that have become increasingly prevalent in rice-growing regions. Recent studies have indicated that mechanized DSR systems improve water productivity and economic returns compared with conventional transplanted rice (Ramesh *et al.*, 2023; Nagargade *et al.*, 2024) ^[2, 8]. Mechanical weeding in line-sown rice has been reported to reduce weed density, improve soil aeration, lower labour dependence, and enhance crop productivity in Direct Seeded Rice (Hashim *et al.*, 2024; Nagargade *et al.*, 2024) ^[9, 8].

Water productivity has become an important criterion for evaluating the sustainability of rice production systems, particularly in irrigated command areas where water resources are under increasing pressure. Recent investigations have demonstrated that direct-seeded rice can substantially improve water productivity while reducing greenhouse gas emissions and cultivation costs compared with conventional transplanting systems (Ghosh *et al.*, 2024) ^[7]. Furthermore, climate-smart rice initiatives promoted by the International Rice Research Institute (IRRI) have highlighted the role of DSR in reducing water consumption, labour use, and production costs while maintaining productivity under irrigated conditions.

Although several studies have documented the advantages of direct-seeded rice, information on the comparative performance of transplanted rice, conventional broadcast direct seeding, and mechanized direct paddy seeding under the irrigated lowland ecosystems of the Mullaiperiyar and Sothuparai river basins of Theni district is limited. Therefore, the present study was undertaken to evaluate different rice establishment methods with respect to water-use efficiency, labour and drudgery reduction, productivity, and profitability in the irrigated lowland ecosystems of Theni district, Tamil Nadu.

Materials and Methods

Experimental Site

The present investigation was conducted as an On-Farm Trial (OFT) during the Kharif seasons of 2023, 2024 and 2025 in farmers fields at Karunkattankulam, Uthmapalayam and Chinnamanur located in the Mullaiperiyar river basin command area of Theni district, Tamil Nadu, India. The study area falls under the Southern Agro-Climatic Zone of Tamil Nadu and is characterized by an irrigated lowland rice ecosystem. The region experiences a tropical semi-arid climate with distinct monsoon seasons.

The climate of Theni district is characterized by warm temperatures throughout the year. During the Kharif 2023 season, the mean maximum and minimum temperatures were 34.2°C and 22.1°C, respectively. The total rainfall received

during the crop period (June–November) was 336 mm. The mean relative humidity ranged from 62 to 79 per cent. In Kharif 2024, the mean maximum temperature was 33.8°C and the minimum temperature was 21.8°C. The crop period received 410 mm of rainfall with relative humidity varying between 60 and 81 per cent. During Kharif 2025, the mean maximum and minimum temperatures were 34.5°C and 22.4°C, respectively. The total rainfall received during the crop-growing period was 326 mm. The relative humidity ranged from 63 to 82 per cent. The rainfall received during the experimental period was primarily contributed by the South-West monsoon, supplemented by irrigation from the Mullaiperiyar river system.

Soil Characteristics

The soil was clay loam in texture with the pH of 6.69, EC is 0.14. The Organic carbon present in the Soil is 0.18 with low in available nitrogen (164 kg ha⁻¹), low in available phosphorus (9.25 kg ha⁻¹), and medium in available potassium (145 kg ha⁻¹). The soil was suitable for irrigated rice cultivation under lowland conditions. The Major cropping system in the trail area is Rice-Rice- Black gram

Experimental Design and Treatments

The experiment was laid out in a Randomized Block Design (RBD) comprising three crop establishment methods with three replications. Individual farmer fields served as replications.

The treatments were,

T₁ – Improved Direct Paddy Seeder

- Sowing using Direct Paddy Seeder
- Row spacing of 20 cm

T₂ – Broadcasting

- Direct broadcasting of pre-germinated seeds

T₃ – Conventional Transplanting

- Nursery raising followed by manual transplanting
- Recommended spacing of 20 × 10 cm

Crop Variety and Crop Management

Rice variety CO 55 was used for all treatments during the study period. The crop was raised following the recommendations of the Tamil Nadu Agricultural University (TNAU) Crop Production Guide for irrigated rice. The recommended fertilizer dose of kg 150:50:50 kg N:P₂O₅:K₂O ha⁻¹ was adopted uniformly for all treatments. Nitrogen was applied in four equal splits at basal, active tillering, panicle initiation and flowering stages. The entire dose of phosphorus and half of potassium were applied as basal, while the remaining potassium was applied in two equal splits at tillering and panicle initiation stages. Irrigation was scheduled according to crop requirement and availability of water from the Mullaiperiyar irrigation system. Plant protection measures were adopted as per TNAU recommendations to maintain a healthy crop stand throughout the growing period. (Crop Production guide, TNAU,2020) ^[10].

Weed Management

In the Improved Direct Paddy Seeder treatment (T₁), mechanical weeding was carried out using a rotary/power weeder at 20–25 and 40–45 days after sowing (DAS). In the broadcasting treatment (T₂), weeds were controlled through manual weeding as practiced by farmers. In the conventional transplanting treatment (T₃), weed management was carried out according to standard recommended practices.

Observations Recorded

Five plants were tagged in each replication on a randomized manner and the yield attributes are observed such as number of hills per m², Number of productive tillers per plant, Number of Productive tillers per m², Panicle length (cm), number of grains per panicle, 1000 grain weight (g) and grain yield.

Resource use parameters

Water Use Parameters

- Total water used (mm)
- Water productivity (kg grain m⁻³ water)

Water productivity was calculated as:

Water Productivity = Water Productivity (kg ha⁻¹ mm⁻¹) = Grain Yield (kg ha⁻¹) / Total Water Used (mm)

Labour and Drudgery Parameters

- Labour requirement (man-days ha⁻¹)
- Labour saving (%)

Labour Saving (%) =

Labour Saving (%) = [(Labour in Conventional Transplanting – Labour in Treatment) / Labour in Conventional Transplanting] × 100

Economic Parameters

- Cost of cultivation (₹ ha⁻¹), Gross return (₹ ha⁻¹), Net return (₹ ha⁻¹), Benefit-cost ratio

Statistical Analysis

The data collected during the three consecutive Kharif seasons were subjected to statistical analysis following the procedures described by Gomez and Gomez (1984) ^[11] for Randomized Block Design (RBD). Analysis of variance (ANOVA) was performed to test the significance of treatment effects. Treatment means were compared using the Critical Difference (CD) test at the 5 per cent level of significance (P = 0.05). the data was tested for statistical significance.

Result and Discussion Yield Attributes

The result revealed that the crop establishment methods significantly influenced the yield attributes of rice. The improved direct paddy seeder (T₁) recorded significantly higher productive tillers per plant (42.67), productive tillers per square meter (1071), panicle length (25.50 cm), grains per panicle (223.33) and 1000-grain weight (18.33 g) compared to broadcasting (T₂) and conventional transplanting (T₃). The superiority of T₁ may be attributed to uniform seed placement, optimum plant spacing, better root development and efficient utilization of growth resources. Line sowing facilitated improved light interception, aeration and nutrient uptake, which enhanced tillering and reproductive development. Similar findings were reported by Ramesh *et al.* (2023) ^[12], who observed superior growth and yield attributes under direct-seeded rice with mechanized sowing compared to conventional establishment methods.

Table 1: Effect of different crop establishment methods on yield attributes and grain yield of rice (Pooled mean of Kharif 2023–2025)

Treatment	No. of Hills m ⁻²	Productive tillers plant ⁻¹	Productive tillers m ⁻²	Panicle length (cm)	Grains panicle ⁻¹	1000-grain weight (g)	Grain yield (q ha ⁻¹)
T ₁ – Improved Direct Paddy Seeder	25.58	42.67	1071.00	25.50	223.33	18.33	61.07
T ₂ – Broadcasting	42.33	21.00	884.00	23.80	200.00	15.67	52.10
T ₃ – Conventional Transplanting	26.00	35.57	936.33	22.75	213.00	16.50	55.86
SEd	1.056	1.698	35.00	0.39	1.587	0.527	1.628
CD (P=0.05)	3.011	4.842	99.78	1.805	4.524	1.503	2.135

Broadcasting (T₂) recorded the highest number of hills per square meter (42.33), but significantly lower productive tillers per plant and productive tillers per unit area. This could be due to excessive plant population resulting in intense intra-specific competition for nutrients, moisture and sunlight. Consequently, individual plant performance and sink development were adversely affected. Similar observations were reported by Ghosh *et al.* (2024) ^[7] who noted reduced yield attributes in broadcast-seeded rice owing to poor crop geometry and increased plant competition.

Grain Yield

Significant differences in grain yield were observed among the crop establishment methods. The improved direct paddy seeder (T₁) recorded the highest grain yield of 61.07 q ha⁻¹, which was significantly superior to broadcasting (52.10 q ha⁻¹) and conventional transplanting (55.86 q ha⁻¹).

The grain yield advantage of T₁ over T₂ and T₃ was 17.2 and 9.3 per cent, respectively. The higher yield achieved under the direct paddy seeder treatment was mainly due to increased productive tillers per unit area, longer panicles, higher grains per panicle and greater test weight. Uniform crop establishment and timely mechanical weeding in line-sown rice would have reduced crop-

weed competition and improved resource-use efficiency, resulting in higher productivity.

Conventional transplanting (T₃) produced an intermediate grain yield of 55.86 q ha⁻¹. Although transplanting maintained optimum plant population, delayed transplanting and temporary transplanting shock might have reduced early crop vigour compared with direct seeding. Broadcasting (T₂) recorded the lowest grain yield (52.10 q ha⁻¹), primarily because of uneven crop establishment, poor crop geometry and greater competition among plants.

The present findings corroborate the reports of Nagargade *et al.* (2024) ^[8], who observed enhanced productivity in line-seeded direct-seeded rice due to improved plant stand and efficient weed management. Similar results were also reported by Hashim *et al.* (2024) ^[9], who concluded that mechanized direct seeding improves yield performance by facilitating better crop establishment and resource utilization.

Overall, the results clearly demonstrated that the improved direct paddy seeder technology was superior to broadcasting and conventional transplanting in enhancing yield attributes and grain yield under the irrigated lowland ecosystems of the Mullaiperiyar river basin of Theni district.

Table 2: Seed rate, water use, water productivity, labour use and economics of rice under different crop establishment methods (Pooled mean of Kharif 2023–2025)

Particulars	T ₁ – Improved Direct Paddy Seeder	T ₂ – Broadcasting	T ₃ – Conventional Transplanting
Seed rate (kg ha ⁻¹)	20	80	60
Irrigation quantity (mm)	520	650	780
Irrigation water saving (%)	33.3	16.7	-
Total water used (mm)*	887	1007	1137
Water productivity (kg ha ⁻¹ mm ⁻¹)	6.96	5.17	4.91
Labour use (man-days ha ⁻¹)	58	78	118
Labour saving (%)	50.8	33.9	-
Cost of cultivation (₹ ha ⁻¹)	41,280	48,529	53,480
Gross return (₹ ha ⁻¹)	134,347	114,613	122,885
Net return (₹ ha ⁻¹)	93,067	66,084	69,405
Benefit-cost ratio	3.25	2.36	2.30

*Total water used = Irrigation water + effective rainfall received during the crop period.

The Improved Direct Paddy Seeder (T₁) required only 20 kg seed ha⁻¹ compared to 80 kg ha⁻¹ under broadcasting and 60 kg ha⁻¹ under conventional transplanting, resulting in seed savings of 75.0 and 66.7 per cent, respectively. The technology also reduced irrigation water requirement by 33.3 per cent compared to transplanted rice owing to the elimination of puddling and reduced standing water requirement during crop establishment (Virendar Kumar *et al.*, 2011)^[12]. Consequently, T₁ recorded the highest water productivity (6.96 kg ha⁻¹ mm⁻¹), which was 43.0 and 32.9 per cent higher than conventional transplanting and broadcasting, respectively. Labour requirement was substantially reduced under direct paddy seeding (58 man-days ha⁻¹) due to mechanized sowing and mechanical weeding, resulting in labour savings of 50.8 per cent over conventional transplanting method. The similar findings also reported by Kamboj *et al.*, 2021^[13]. Pathak *et al.* (2011)^[14] reported that direct-seeded rice has significant potential for reducing water use, labour requirement and production costs while maintaining productivity. The combined effect of lower seed rate, reduced irrigation demand, decreased labour requirement and higher grain yield resulted in superior economic returns, with a net return of ₹93,067 ha⁻¹ and a benefit-cost ratio of 3.25. These results clearly demonstrate that the Improved Direct Paddy Seeder technology is a climate-resilient rice establishment method capable of conserving water, reducing labour drudgery, improving resource-use efficiency and enhancing farm profitability in the irrigated lowland ecosystems of the Mullaiperiyar river basin. (Chandrasekhararao *et al.*, 2013)^[15].

Economics

The economics of rice cultivation were markedly influenced by the crop establishment methods adopted under the irrigated lowland ecosystem of the Mullaiperiyar river basin. Among the treatments, the Improved Direct Paddy Seeder (T₁) recorded the lowest cost of cultivation (₹41,280 ha⁻¹) and the highest gross return (₹134,347 ha⁻¹), resulting in the maximum net return (₹93,067 ha⁻¹) and benefit-cost ratio (3.25). Dey *et al.* (2025)^[17] also reported that higher net return in DSR method as compared to conventional method. The superior profitability of T₁ was mainly attributed to reduced expenditure on nursery raising, transplanting and manual weeding, coupled with higher grain yield achieved through uniform crop establishment and efficient resource utilization. In contrast, broadcasting (T₂) incurred a cultivation cost of ₹48,529 ha⁻¹ and generated a net return of ₹66,084 ha⁻¹ with a benefit-cost ratio of 2.36, while conventional transplanting (T₃) registered the highest cultivation cost (₹53,480 ha⁻¹) due to labour-intensive operations and produced a net return of ₹69,405 ha⁻¹ with a benefit-cost ratio of

2.30. The Improved Direct Paddy Seeder enhanced net returns by 40.8 and 34.1 per cent over broadcasting and conventional transplanting, respectively, demonstrating its economic superiority (Anilkumar *et al.*, 2025)^[16]. The higher profitability achieved under mechanized direct seeding highlights its potential as a cost-effective and climate-resilient rice establishment technology capable of reducing production costs, labour dependency and drudgery while maximizing farm income in the irrigated lowland ecosystems of Theni district. These findings are in conformity with the reports of Ramesh *et al.* (2023)^[2] and Nagargade *et al.* (2024)^[8], who observed higher profitability and resource-use efficiency under mechanized direct-seeded rice systems compared with conventional rice establishment methods.

Conclusion

The three-year On-Farm Trial conducted in the irrigated lowland ecosystems of the Mullaiperiyar River Basin clearly demonstrated that the Improved Direct Paddy Seeder is a climate-smart and resource-conserving rice establishment technology capable of enhancing productivity while reducing dependence on water, seed and labour inputs as compared to broadcasting and conventional transplanting. In addition, it achieved substantial resource savings through a 75 per cent reduction in seed requirement, 33.3 per cent irrigation water saving, and 50.8 per cent labour saving, while significantly reducing drudgery associated with nursery raising, transplanting and manual weeding. The integration of mechanized sowing and mechanical weed management improved resource-use efficiency and operational timeliness, which are critical under changing climatic conditions and increasing labour scarcity. Therefore, the Improved Direct Paddy Seeder technology can be recommended as a sustainable climate-smart intervention for enhancing productivity, conserving water, reducing production costs and strengthening the resilience of rice-based farming systems in Tamil Nadu and similar irrigated ecosystems.

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