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SUSTAINABLE MECHANIZED RICE ESTABLISHMENT SYSTEM IN KOSI REGION OF BIHAR INDIA

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ABSTRACT

Rice cultivation in eastern India is increasingly constrained by labour scarcity, rising wage rates, and high-water demand associated with conventional puddled transplanting. Direct Seeded Rice (DSR) has emerged as a promising alternative to address these challenges through mechanization and conservation agriculture practices. An On-Farm Trial (OFT) was conducted during Kharif 2024 and 2025 to assess the adoption and impact of different DSR technologies in a paddy-based cropping system. Three technology options (TO) were evaluated: TO I–Farmers' Practice (manual transplanting), TO II–DSR with zero till multi-crop planter, and TO III–DSR with super seeder. Each treatment was implemented on one hectare under farmers field conditions. Results showed that manual transplanting produced the highest grain yield (46.0 q/ha), however, DSR technologies significantly reduced cost of cultivation (35–40%). DSR with zero till multi-crop planter (TO II) recorded the highest net return (Rs. 77,270/ha) and benefit–cost (BC) ratio (3.06), followed by DSR with super seeder (BC ratio 2.76). Despite a marginal yield reduction (4–6%), mechanized DSR proved economically superior and more resource-efficient intervention. Adoption assessment of said technology indicated positive farmer's response towards DSR due to labour saving, lower production cost, and timely sowing. The study concludes that DSR, particularly with zero till multi-crop planter, is a viable and scalable technology for sustainable rice production in paddy-based cropping systems.
Keywords **:** Direct Seeded Rice, mechanization, zero till planter, super seeder, adoption, profitability, paddy-based cropping system

Introduction

Rice (*Oryza sativa* L.) is the most important staple food crop of India and plays a central role in ensuring food and livelihood security, particularly in eastern India where rice-based cropping systems dominate (FAO, 2021). Conventionally, rice cultivation in this region relies on puddled transplanting, which is preferred for its advantages of better crop establishment and weed suppression (Bouman *et al.*, 2007). However, puddled transplanted rice is increasingly becoming unsustainable due to its high labour requirement, excessive water use, and rising production costs (Kumar and Ladha, 2011; Chauhan *et al.*, 2012). Labour scarcity during peak transplanting season, coupled with rising wage rates and erratic monsoon rainfall, has emerged as a major challenge for rice farmers, often resulting in delayed transplanting and reduced system productivity (Pathak *et al.*, 2013). Participatory Rural Appraisal (PRA) conducted prior to the present study revealed that labour shortage, high cost of transplanting, delayed planting due to erratic rainfall, and high irrigation requirement were the most severe constraints affecting rice cultivation. Similar constraints have been widely reported in rice-growing regions of eastern Indo-Gangetic Plains (Singh *et al.*, 2018; Jat *et al.*, 2020). Direct Seeded Rice (DSR) has emerged as a viable alternative to conventional transplanting, as it eliminates nursery raising and transplanting operations, thereby reducing labour demand, water use, and energy consumption (Farooq *et al.*, 2011; Rao *et al.*, 2017). Mechanized DSR using zero till multi-crop planters and super seeders further enhances operational efficiency and timeliness of sowing (Gathala *et al.*, 2014). Despite these advantages, adoption of DSR remains limited due to concerns related to weed management, crop establishment, and yield stability (Chauhan, 2013).

Therefore, systematic year-wise assessment with statistical validation under farmers' field conditions is essential to evaluate the performance, economic viability, and adoption potential of mechanized DSR technologies. The present study was undertaken to assess the adoption and impact of DSR technologies during Kharif 2024 and 2025, with special emphasis on productivity, profitability, and resource use efficiency in a paddy-based cropping system.

Materials and Methods

Study area and location of On-Farm Trial

The On-Farm Trial (OFT) was conducted during Kharif 2024 and 2025 in Purnea district of Bihar, India, which falls under the Eastern Indo-Gangetic Plains and is characterized by a humid subtropical climate with monsoon-dependent rice cultivation. The district represents a typical paddy-based production system with rice as the dominant kharif crop followed by maize and mung during rabi and summer seasons. Based on preliminary surveys and Participatory Rural Appraisal (PRA) exercises, four representative villages were selected for implementation of the OFT to ensure coverage of different micro-situations and farmer categories. The selected villages were: 1. Basantpur (25°85′ N, 87°56′ E), 2. Taljhari (25°86′ N, 87°55′ E), 3. Kullasundar (25°86′ N, 87°55′ E) and Katheli (25°86′ N, 87°50′ E). These villages are characterized by medium to heavy textured alluvial soils, assured monsoon rainfall, and widespread adoption of conventional manual transplanting. The study locations were selected due to acute labour shortage during transplanting season, high cost of cultivation, and increasing interest among farmers in mechanized rice establishment methods.

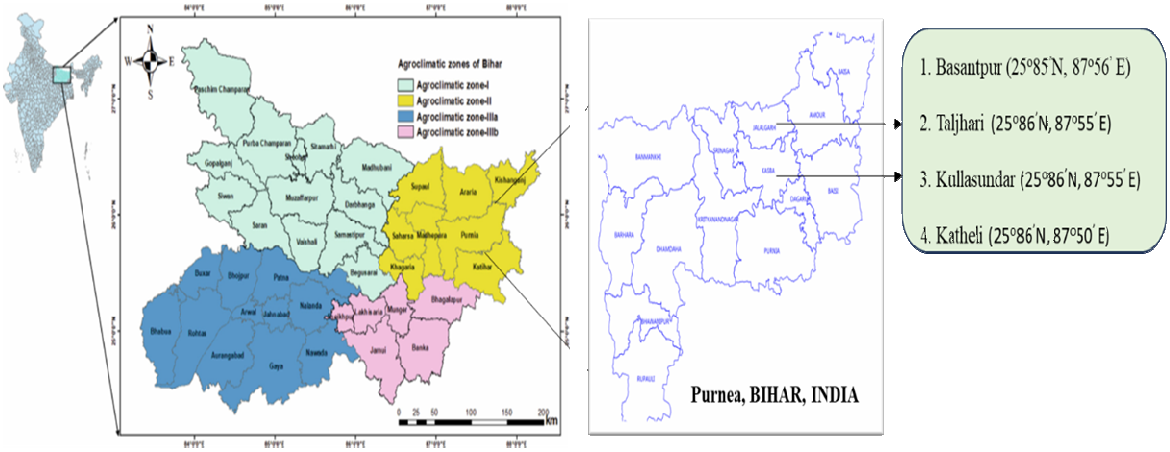

Fig. 1 The geographical location of the study area and distribution of selected OFT villages

Problem identification and prioritization using Participatory Rural Appraisal (PRA)

Prior to initiation of the On-Farm Trial (OFT), Participatory Rural Appraisal (PRA) was conducted during pre-kharif season (April–May) in the selected villages to identify and prioritize major constraints associated with existing rice establishment practices (Chambers, 1994). PRA was undertaken to ensure that the OFT addressed farmer-perceived problems based on severity and impact, rather than researcher assumptions. A total of 30 rice-growing farmers (small, marginal, and medium categories) were involved in PRA exercises through group interactions and field-level discussions (Pretty, 1995; Singh *et al.*, 2019). Focused group discussions were conducted with farmers to document prevailing rice cultivation practices, operational bottlenecks, and economic challenges. Farmers unanimously reported that manual transplanting is becoming increasingly difficult to manage due to labour unavailability and rising wage rates.

Problem listing and severity ranking

Farmers identified major constraints and ranked them based on 1. Severity of the problem, 2. Frequency of occurrence and 3. Impact on cost of cultivation and crop yield. Each problem was scored on a 1–5 scale (1 = low severity, 5 = very high severity). Mean severity scores were calculated to prioritize constraints. Based on PRA outcomes, labour-intensive transplanting, high cost of operation, and water scarcity the OFT was formulated to assess Direct Seeded Rice (DSR) technologies using zero till multi-crop planter and super seeder as potential solutions to the prioritized problems.

Table 1 : Major problems identified through PRA and their severity ranking (n = 30 farmers)

S.N.	Problem identified	Mean severity score (1–5)	Rank
1	Acute shortage of labour during transplanting period	4.8	I
2	High cost of manual transplanting due to rising wage rates	4.6	II
3	Delay in transplanting due to erratic monsoon rainfall	4.4	III
4	High irrigation requirement and water scarcity during puddling	4.2	IV
5	Increased cost of nursery raising and management	3.9	V
6	Drudgery and long working hours in transplanting	3.8	VI
7	Difficulty in timely land preparation due to repeated tillage	3.6	VII
8	Poor timeliness affecting sowing of succeeding rabi crops	3.5	VIII
9	Rising fuel and energy cost for multiple field operations	3.4	IX
10	Low availability of skilled transplanting labour	3.3	X

Statistical indicators and analytical framework

To ensure robust interpretation of the year-wise performance of Direct Seeded Rice (DSR) technologies and to validate treatment differences under farmers' field conditions, appropriate statistical indicators were employed (Gomez and Gomez, 1984). These indicators were selected to capture variability among farmers, significance of treatment effects, and economic superiority of technologies. The following statistical parameters were computed and used for interpretation in the Results and Discussion sections:

Mean ($\bar{x}$): Mean values of yield, cost of cultivation, gross return, net return, fuel consumption, and field capacity were calculated from observations recorded from 10 farmers per treatment per year. Mean values represent the average performance of each technology under real farm conditions.

Standard Error of Mean (SEm ±): SEm was calculated to assess variability among farmers within a treatment. It provides an estimate of the precision of the mean and reflects the stability of the technology across locations and years.

Coefficient of Variation (CV %): CV was computed to evaluate relative variability of yield and economic parameters among treatments. Lower CV values indicate higher consistency and reliability of a technology across farmers' fields.

Critical Difference (CD) at 5% probability level ($p = 0.05$): Treatment means were compared using CD to determine whether observed differences were statistically significant. Differences exceeding the CD value were considered significant, while those below the CD were treated as non-significant.

Results

Grain yield performance

The statistically significant yield advantage observed under manual transplanting agrees with earlier findings that standing water suppresses weeds and improves crop establishment (Bouman *et al.,* 2007; Chauhan *et al.,* 2012). The year-wise and mean grain yield of rice under manual transplanting and mechanized DSR technologies, along with associated statistical indicators (Table 1). Manual transplanting (TO I) recorded the highest grain yield during both Kharif 2024 (45.6 q ha^{-1}) and Kharif 2025 (46.4 q ha^{-1}), resulting in a pooled mean yield of 46.0 q ha^{-1}. The superior yield under transplanting can be attributed to better crop establishment, uniform plant population, and effective weed suppress ion under continuous standing water. DSR with zero till multi-crop planter (TO II) recorded grain yields of 43.9 q ha^{-1} in 2024 and 44.5 q ha^{-1} in 2025, while DSR with super seeder (TO III) yielded 43.2 q ha^{-1} and 44.0 q ha^{-1} during the respective years. The observed yield reduction under DSR treatments was marginal (approximately 4–6%) compared to transplanting and similar results were observed by (Farooq *et al.*, 2011; Rao *et al.*, 2017). Statistical analysis indicated that the yield difference between manual transplanting and DSR treatments was statistically significant at the 5% probability level, as the differences exceeded the critical difference (CD). However, the yield difference between TO II and TO III was statistically non-significant, indicating comparable yield performance between the two mechanized DSR options. The low coefficient of variation (CV: 2.62–2.85%) reflects high consistency of yield performance across farmers in both years.

Table 1 : Grain yield of rice under different establishment methods (Mean of two years' data)

Technical Options (TO)	Kharif 2024 (q ha^{-1})	Kharif 2025 (q ha^{-1})	Mean (q ha^{-1})
TO I – Manual transplanting	45.6 ± 0.48	46.4 ± 0.42	46.0
TO II – DSR (ZT multi-crop planter)	43.9 ± 0.46	44.5 ± 0.44	44.2
TO III – DSR (Super seeder)	43.2 ± 0.51	44.0 ± 0.49	43.6
SEm (±)	0.39	0.36	—
CD (p = 0.05)	1.12	1.05	—
CV (%)	2.85	2.62	—

Values are mean ± SEm of 10 farmers. Differences between treatment means exceeding CD at 5% probability level are considered statistically significant. CV = coefficient of variation.

Cost of cultivation

The year-wise cost of cultivation associated with different rice establishment methods display in Table 2. Manual transplanting incurred the highest cost of cultivation, with values of Rs. 41,200 ha^{-1} in 2024 and Rs. 41,800 ha^{-1} in 2025, resulting in a mean of Rs. 41,500 ha^{-1}. The higher cost under this practice is mainly due to labour-intensive nursery raising, puddling, transplanting operations, and higher irrigation requirement. In contrast, DSR technologies substantially reduced the cost of cultivation. DSR with zero till multi-crop planter (TO II) recorded the lowest cost (Rs. 25,000 ha^{-1} in 2024 and Rs. 25,500 ha^{-1} in 2025), representing a cost reduction of nearly 39% over manual transplanting. DSR with super seeder (TO III) also significantly reduced cultivation cost (Rs. 26,600–27,200 ha^{-1}), although it remained slightly higher than TO II due to increased fuel consumption and higher tractor power requirement. Statistical analysis confirmed that differences in cost of cultivation among treatments were significant (p = 0.05). The CV values (3.9–4.1%) indicate low variability in cost across farmers, highlighting the economic stability and repeatability of cost savings under DSR technologies. The significantly lower cost of cultivation under DSR treatments corroborates earlier reports highlighting labour and water savings under direct seeding systems (Kumar and Ladha, 2011; Gathala *et al.,* 2014).

Table 2 : Cost of cultivation under different rice establishment methods

Treatment	Kharif 2024 (Rs. ha^{-1})	Kharif 2025 (Rs. ha^{-1})	Mean (Rs. ha^{-1})
TO I – Manual transplanting	41,200	41,800	41,500
TO II – DSR (ZT multi-crop planter)	25,000	25,500	25,250
TO III – DSR (Super seeder)	26,600	27,200	26,900
SEm (±)	620	650	—
CD (p = 0.05)	1,780	1,860	—
CV (%)	3.9	4.1	—

*Cost data analysed using farmer-wise observations (n = 10). Significant differences were tested at p = 0.05.

Economic performance and profitability

A comprehensive economic comparison of rice establishment methods by jointly presenting cost of cultivation, gross return, net return, and benefit–cost ratio presented in Table 3. Inclusion of cost of cultivation alongside returns enables a clearer understanding of how profitability under different treatments is driven more by cost efficiency than by yield alone. Manual transplanting (TO I) consistently recorded the highest cost of cultivation, averaging Rs. 41,500 ha^{-1} across two years. This high cost is mainly attributed to labour-intensive nursery raising, puddling, and transplanting operations, along with higher irrigation demand. Although TO I achieved the highest grain yield, its high production cost substantially reduced economic efficiency, resulting in the lowest mean net return (Rs. 65,220 ha^{-1}) and BC ratio (1.57). In contrast, DSR with zero till multi-crop planter (TO II) recorded the lowest cost of cultivation (Rs. 25,250 ha^{-1}), representing a statistically significant reduction (p = 0.05) of nearly 39% compared to manual transplanting. Despite a marginal yield reduction, this drastic cost saving translated into the highest net return (Rs. 77,270 ha^{-1}) and a consistently superior BC ratio of 3.06 in both years. The low CV (5.2%) for net returns indicates that these economic gains were stable and repeatable across farmers and seasons. DSR with super seeder (TO III) also significantly reduced cost of cultivation (Rs. 26,900 ha^{-1}) compared to manual transplanting, though it remained slightly higher than

TO II due to greater fuel consumption and higher tractor power requirement. Nevertheless, TO III achieved a mean net return of Rs. 74,250 ha^{-1} and a BC ratio of 2.76, clearly outperforming the farmers' practice. Statistical analysis shows that differences in cost of cultivation and net return between manual transplanting and both DSR treatments were significant, whereas differences between TO II and TO III were relatively smaller. These results clearly demonstrate that cost reduction is the dominant factor driving profitability under DSR, validating farmers' preference for mechanized DSR technologies. Higher net returns and BC ratios under DSR, despite slightly lower yields, indicate that cost efficiency is a stronger determinant of profitability than yield alone, as also reported by Singh *et al.* (2018) and Pathak *et al.* (2013).

Table 3 : Economic returns and B:C ratio under different establishment methods

Treatment	Year	Cost of cultivation (Rs. ha^{-1})	Gross return (Rs. ha^{-1})	Net return (Rs. ha^{-1})	BC ratio
TO I – Manual transplanting	2024	41,200	1,05,480	64,280	1.56
	2025	41,800	1,07,960	66,160	1.58
	Mean	41,500	1,06,720	65,220	1.57
TO II – DSR (ZT multi-crop planter)	2024	25,000	1,01,610	76,610	3.06
	2025	25,500	1,03,430	77,930	3.13
	Mean	25,250	1,02,520	77,270	3.09
TO III – DSR (Super seeder)	2024	26,600	1,00,120	73,520	2.76
	2025	27,200	1,02,180	74,980	2.92
	Mean	26,900	1,01,150	74,250	2.84
SEm (±)	—	635	—	1,520	—
CD (p = 0.05)	—	1,820	—	4,350	—
CV (%)	—	4.0	—	5.2	—

Operational and energy efficiency indicators

Lower fuel consumption and higher field efficiency observed under zero till multi-crop planter agree with findings of Gathala *et al.* (2014), who reported improved energy use efficiency and timeliness under conservation agriculture-based rice systems. The operational and energy efficiency parameters of mechanized DSR technologies highlighted in Table 4. DSR with zero till multi-crop planter (TO II) recorded lower fuel consumption (11.0 L ha^{-1}) compared to super seeder (16.0 L ha^{-1}), reflecting lower energy requirement due to fewer moving components and lower tractor power demand. Field capacity was comparable between the two machines, with TO II and TO III recording 0.60 and 0.62 ha h^{-1}, respectively. However, TO II exhibited higher field efficiency (70%) than TO III (66%), indicating better operational effectiveness under farmers' field conditions. Low CV values (<6%) for fuel consumption and field performance parameters demonstrate uniform machine performance across locations. These operational advantages directly contribute to timely sowing and reduced labour dependency

Table 4 : Operational performance of DSR technologies

Treatment	Fuel consumption (L ha^{-1})	Field capacity (ha h^{-1})	Field efficiency (%)
TO II – DSR (ZT multi-crop planter)	11.0	0.60	70.0
TO III – DSR (Super seeder)	16.0	0.62	66.0
CV (%)	6.4	5.8	4.9

Discussion

The statistically analyzed results clearly demonstrate that manual transplanting produced significantly higher grain yield than DSR treatments in both years, as the yield differences exceeded the CD (p = 0.05). This yield advantage can be attributed to better crop establishment and effective weed suppression under standing water. However, the yield difference between the two DSR treatments (TO II and TO III) was statistically non-significant, indicating comparable biological performance of both mechanized DSR options. Despite the statistically significant yield advantage of transplanting, cost of cultivation differed significantly (p = 0.05) among treatments, with DSR technologies recording 35–40% lower costs than manual transplanting. The low CV values (<5%) for cost data indicate high consistency of cost savings across farmers and years. This directly validates the PRA-identified top constraints of labour scarcity and high transplanting cost. Economic analysis further revealed that net returns and BC ratios were significantly higher under DSR treatments, particularly TO II. Although yield reduction under DSR was statistically significant, the magnitude of reduction (4–6%) was economically compensated by substantial cost savings, resulting in a statistically superior profitability. The consistently higher BC ratio (3.06) of TO II across both years highlights its robustness and adoption potential. Operational indicators further strengthen these findings. Lower fuel consumption and higher field efficiency under TO II indicate better energy use efficiency and timeliness of operation. These results are in strong agreement with PRA findings, where farmers prioritized labour saving, reduced drudgery, and timely sowing over marginal yield gains. Overall, the convergence of statistical significance, low variability (CV%), and farmer-perceived benefits confirms that mechanized DSR, especially with zero till multi-crop planter is a technically sound, economically superior, and farmer-relevant alternative to conventional transplanting in paddy-based cropping systems. These findings are in line with earlier research emphasizing DSR as a climate-smart and resource-efficient rice establishment method (Farooq *et al*., 2011; Pathak *et al*., 2013).

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