Agric Res J **61** (3): 369-376, *June* 2024
DOI: 10.5958/2395-146X.2024.00048.2

AN ECONOMIC ANALYSIS OF ENERGY USE IN PADDY CULTIVATION: A COMPARATIVE STUDY OF DIRECT SEEDED RICE (DSR) VS PUDDLED TRANSPLANTED RICE (PTR) PRACTICES IN PUNJAB, INDIA

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ABSTRACT

Agriculture and energy consumption have a strong relationship, and achieving agricultural sustainability relies on a balance of production, environmental, and economic factors. A comparative analysis of two paddy cultivation systems—Direct Seeded Rice (DSR) and Puddled Transplanted Rice (PTR)—conducted in Punjab during the agricultural year 2021-22, revealed notable differences in energy use. Both input and output energy levels were lower on DSR farms, measuring 21,708.61 MJ/acre and 87,431 MJ/acre, respectively, compared to PTR farms, which recorded 24,816.79 MJ/acre for input energy and 88,451 MJ/acre for output energy. Despite the higher total input energy in the PTR method—approximately 13% greater than that of DSR—the net energy gain for DSR was more favourable at 65,722.57 MJ/acre, compared to 63,634.26 MJ/acre for PTR. In both systems, chemical fertilizers emerged as the primary energy source, accounting for approximately 41% to 42% of total input energy, with nitrogenous fertilizers contributing the largest share. The energy intensity of PTR was notably high at 8.86 MJ/kg, indicating substantial potential for enhancing energy productivity in rice cultivation under this method. Additionally, total variable costs (TVC) were approximately 16% lower for DSR, amounting to Rs 23,344.06 per acre, in contrast to Rs 27,677.33 per acre for PTR. Human labour constituted the largest expense, representing around 23% of costs in DSR and 33% in PTR. Although DSR produced marginally lower yields—2,769 kg per acre compared to 2,801.3 kg per acre for PTR—the net Return on Variable Costs (ROVC) was approximately 13% higher in DSR, at Rs 31,482.14 per acre versus Rs 27,788.41 per acre for PTR, primarily due to lower variable costs associated with DSR. The production cost per kilogram of grain using DSR was calculated at Rs 8.43, which is about 15% less than the cost of Rs 9.88 per kilogram in PTR. These findings suggest that DSR is a resource- and cost-efficient technology for paddy cultivation. To facilitate its broader adoption, there is a need to enhance farmer awareness of recommended DSR production practices and the associated benefits.

Keywords: Energy consumption, Benefits, Cost, Input energy

There is a strong relationship between agriculture and energy consumption, with agricultural sustainability dependent on a balance of production, environmental, and economic factors. Energy serves as a critical input in agriculture, which effectively transforms energy into products that enhance food security, add value, and stimulate rural economies (FAO, 2000). As global populations rise and food production intensifies, reliance on non-renewable energy sources has increased, placing continuous strain on natural resources and jeopardizing the viability of agricultural systems (Basavaligaiah *et al*., 2020). In this context, the efficient use of energy within the agricultural sector emerges as a fundamental requirement for sustainable practices. This efficiency not only facilitates financial savings and the conservation of fossil resources but also mitigates air pollution (Pervanchon *et al*., 2002). Agriculture is increasingly recognizing the advantages of resource conservation and effective resource management as pathways to cleaner and more sustainable outputs (Kumar *et al*., 2019). Advancements in agricultural technology have largely depended on increased energy inputs and improvements in energy quality. A critical focus has emerged on enhancing energy efficiency—either by increasing agricultural output with existing energy levels or by reducing energy consumption without compromising current production levels. The declining energy-use efficiency observed in contemporary agriculture raises significant concerns, prompting the necessity for optimal and efficient utilization of energy inputs across diverse agricultural practices (Kumar *et al*., 2020).

Approximately 70 percent of the Indian population relies on rice as their primary food source, which occupies 40 to 45 percent of the land dedicated to cereal crops in India. To meet the increasing demand for rice, it is essential to enhance production efficiency while minimizing agricultural input energy use. Over the past

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Date of receipt: 31.03.2023, Date of acceptance: 08.05.2024

decade, the Indian economy has undergone significant changes, with farm labour migrating to industries offering better wages and working conditions. This shift has resulted in a sharp increase in labour costs for rice production, thereby impacting its profitability (Bhullar *et al.*, 2018). In light of the impending water crisis and the water-intensive nature of traditional rice farming, there is a pressing need to explore alternative management techniques that enhance water productivity. Given the global constraints on water resources, direct seeded rice (DSR) emerges as a viable alternative to conventional practices (Farooq *et al.*, 2011). Transitioning from traditional puddled transplanted rice (PTR) to DSR is crucial, as DSR not only reduces water consumption and labour requirements but also helps maintain soil structure amidst rapid groundwater depletion (Bandumala *et al.*, 2018). Furthermore, DSR is advantageous in terms of cost, energy, and time efficiency, while also being environmentally friendly (Jat *et al.*, 2022). As a conservation tillage practice, DSR significantly lowers energy consumption, carbon input, and greenhouse gas (GHG) emissions compared to the PTR method (Basavalingaiah *et al.*, 2020).

Punjab, which constitutes merely 1.54 percent of India's total geographical area, is recognized as one of the country's most progressive states. Approximately 3.1 million hectares of its land are devoted to rice cultivation, which plays a pivotal role in ensuring national food security. Over the past decade, Punjab has contributed about 25 to 30 percent of the rice and 35 to 40 percent of the wheat to India's central pool (PAU, 2022). However, the increasing reliance on commercial energy by Punjab's farmers has led to a highly energy-intensive agricultural system. Research indicates that the choice between transplanting and direct seeded rice (DSR) often hinges on the availability of water and labour costs: transplanting is favoured when water is abundant and labour costs are low, whereas DSR is preferred in conditions of high labour costs and water scarcity (Kaur and Singh, 2017). Furthermore, there exists significant potential for enhancing production on farms with lower efficiency through improved management and better allocation of resources and technologies (Samarpitha *et al.*, 2016). In light of these considerations, the present study aims to compare the two paddy cultivation systems—transplanting and DSR—focusing on energy use and economic implications.

MATERIALS AND METHODS

This study was conducted in Punjab during the agricultural year 2021-22 to achieve the specified objectives. A multi-stage random sampling technique was employed to select the study sample. Initially, Sri Mukatsar Sahib district was identified as having the largest area under Direct Seeded Rice (DSR) technology for paddy cultivation, based on consultations with officials from the Punjab State Department of Agriculture. In the second stage, two blocks—Gidderbaha and Mukatsar—were selected due to their significant concentration of DSR technology (Table 1). In the final stage, two villages from each block that exhibited widespread adoption of DSR were chosen for the study. Specifically, Kauni and Doda villages were selected from the Gidderbaha block, while Bhullar and Thandewala villages were chosen from the Mukatsar block.

Using a simple random sampling technique, 20 farmers who adopted Direct Seeded Rice (DSR) were selected from each chosen village for the study. To assess the impact of DSR technology, ten non-adopter farmers from the same areas were included as a control group. Consequently, the total sample for this study consisted of 120 farmers, comprising 80 DSR adopters and 40 non-adopters.

In alignment with the study's objectives, a comprehensive interview schedule was developed to collect primary data on two cultivation practices: Direct Seeded Rice (DSR) and Puddled Transplanted Rice (PTR). Data were gathered through personal interviews with the selected farmers. The interview covered various inputs utilized in paddy cultivation, including seed, diesel fuel (used for multiple farm operations such as seedbed preparation, inter-cultivation, harvesting, and transportation), fertilizers, farmyard manure (FYM), and chemicals (insecticides, fungicides, and herbicides). Additionally, information on crop yield, total labour hours (including both men and women), draught power employed for various farm tasks, and total machinery working hours were recorded. The data on paddy grain yield were further utilized to estimate straw yield using

Table 1. Sampling design

District	Block	Village	DSR Adopters	DSR Non- Adopters	Total
Sri Mukatsar Sahib	Gidderbaha	Kauni	20	10	30
		Doda	20	10	30
	Mukatsar	Bhullar	20	10	30
		Thandewala	20	10	30
Grand Total			80	40	120

the crop-to-residue ratio method (Chauhan, 2012).

Data analysis

A. Estimation of input energy expenditure

The data on inputs used in paddy cultivation, along with the outputs (grain and straw), were converted into energy units by applying embodied energy equivalents for each type of input and output. These values were expressed in megajoules (MJ) using specific energy coefficients sourced from the Research Digest on Energy Requirements in the Agricultural Sector, published by the Department of Farm Power and Machinery, PAU, Ludhiana (Singh and Singh, 2002), as detailed in Table 2.

Table 2. Energy coefficients used in energy calculation for paddy cultivation

Sr. No.	Energy source	Energy coefficient (MJ/unit)
1	Human labour (h)	
	Adult man	1.96
	Adult woman	1.57
2	Animal labour (h)	14.05
3	Fertilizer (kg)	
	N	60.6
	P_2O_5	11.1
	K_2O	6.7
4	Farmyard manure (FYM) in kg	0.3
5	Chemicals (kg)	
	Granular chemicals (kg)	120
	Liquid chemicals (litre)	102
6	Machinery (h)	62.7
7	Diesel (litre)	56.31
8	Seed/Grain (kg)	14.57
9	Straw (kg)	12.5
10	Electricity (KWh)	11.93

Source: Singh and Singh, 2002

To compare how efficiently paddy crop converts input energy into output energy following ratios were carried out.

Specific Energy or Energy Intensity

Specific energy indicates the amount of input energy used to produce a unit of crop yield (grain) and is determined as the ratio of total energy input to crop yield

$$\text{Specific energy} = \frac{\text{Energy input (MJ/acre)}}{\text{Yield (kg/acre)}}$$

Net Energy

The net energy is defined as the difference between energy output and the total energy input. It was obtained by subtracting input energy from output energy.

RESULTS AND DISCUSSION

Energy use in paddy cultivation: DSR vs conventional PTR

The results of this study indicate that farmers utilized energy from nine distinct sources for paddy cultivation, namely human labour, draft animals, machinery, diesel fuel, seeds, fertilizers, farmyard manure (FYM), chemicals, and electricity. A comparative assessment of energy use between the conventional puddled transplanted rice (PTR) method and the direct seeded rice (DSR) method revealed that the total input energy consumption for paddy cultivation was significantly higher in the PTR method, amounting to 24,816.79 MJ/acre, which is approximately 13% greater than the 21,708.61 MJ/acre observed in DSR (Table 3). A component-wise analysis further elucidated these differences. Notably, the contribution of human labour to input energy was substantially higher in the PTR method, totaling 320.4 MJ/acre, which represents an increase of about 38% compared to the DSR method (198.02 MJ/acre). Additionally, the use of machine labour in the PTR method was approximately 7% greater, with values of 252.69 MJ/acre for PTR versus 233.96 MJ/acre for DSR. Similarly, diesel fuel consumption was 8% higher in the PTR method (2,618.4 MJ/acre) compared to DSR (2,407.25 MJ/acre). These differences were found to be statistically significant, highlighting the distinct energy profiles associated with each cultivation method.

The input energy derived from animal labour was also marginally higher in the conventional puddled transplanted rice (PTR) method, with an energy use of 14.05 MJ/acre, compared to 10.54 MJ/acre for the direct seeded rice (DSR) method. On the other hand, the energy consumption associated with seed rate was significantly higher in the DSR method, amounting to 115.98 MJ/acre, compared to 77.91 MJ/acre for PTR. This contrast highlights the differing energy dynamics between the two cultivation approaches, particularly regarding the utilization of animal labour and seed inputs.

The energy use associated with chemical fertilizers, specifically in terms of nitrogen (N), phosphorus (P), potassium (K), and micronutrients (zinc and iron sulfate), was lower in the direct seeded rice (DSR) method compared to the conventional puddled transplanted rice (PTR) method. The energy inputs were estimated at approximately 8,643 MJ/acre for nitrogen, 73 MJ/acre for phosphorus, 41 MJ/acre for potassium, 107 MJ/acre for zinc, and 58 MJ/acre for iron sulfate in DSR, whereas in PTR, these values were 10,340 MJ/

Table 3. **Energy consumption patterns in paddy cultivation by DSR and TPR methods by the respondents (2021-22)**

Sr. No.	Input/Energy Use	Energy use (MJ/acre)		Mean difference	% change over PTR
		DSR	PTR		
1	Human Labour	198.02 (0.91)	320.40 (1.29)	-122.38	-38.20
2	Animal Labour	10.54 (0.05)	14.05 (0.06)	-3.51	-24.98
3	Machine Labour#	233.96 (1.08)	252.69 (1.02)	-18.73	-7.41
4	Diesel	2407.25 (11.09)	2618.40 (10.55)	-211.15	-8.06
5	Seed	115.98 (0.53)	77.91 (0.31)	38.07	48.86
6	Fertilizers and micro nutrients				
A	Nitrogen	8642.94 (39.81)	10339.57 (41.66)	-1696.63	-16.41
B	Phosphorus	72.59 (0.33)	75.48 (0.30)	-2.89	-3.83
C	Potassium	41.14 (0.19)	45.56 (0.18)	-4.42	-9.70
D	Zinc	107.22 (0.49)	135.85 (0.55)	-28.63	-21.07
E	Iron Sulphate	58.23 (0.27)	46.00 (0.19)	12.23	26.59
F	Others##	31.80 (0.15)	27.00 (0.11)	4.80	17.78
7	FYM	1722 (7.93)	1800 (7.25)	-78	-4.33
8	Plant Protection Chemicals				
A	Rodenticide	185.98 (0.86)	60.00 (0.24)	125.98	209.97
B	Insecticide	275.44 (1.27)	227.46 (0.92)	47.98	21.09
C	Weedicide	327.62 (1.51)	122.40 (0.49)	205.22	167.66
9	Electricity	7277.90 (33.53)	8654.02 (34.87)	-1376.12	-15.90
I	Total energy use	21708.61 (100.0)	24816.79 (100.0)	-3108.18	-12.52
II	Total output energy	87431.18	88451.05	-1019.87	-1.15
III	Net Energy	65722.57	63634.26	2088.31	3.28
IV	Energy Intensity (MJ/kg)	7.84	8.86	-1.02	-11.51

Figures in the brackets indicate the per cent to total input energy use
#use of tractor for land preparation, irrigation, transport on farm and harvester combine
##seed treatment chemicals and growth regulators

acre for nitrogen, 75 MJ/acre for phosphorus, 46 MJ/acre for potassium, 136 MJ/acre for zinc, and 46 MJ/acre for iron sulfate. Notably, significant differences were observed only in the nitrogen content and the micronutrient zinc between the two methods. In a related study conducted in Bangladesh, inorganic fertilizers constituted a major share (59.98%) of the total energy input in rice cultivation, with nitrogen fertilizers being the predominant source, accounting for 54.94% of the energy input (Rahman *et al.*, 2015). Additionally, the energy consumption associated with farmyard manure (FYM) was higher on PTR farms, recorded at 1,800 MJ/

acre compared to 1,722 MJ/acre on DSR farms. These findings further illustrate the distinct energy profiles associated with each cultivation method.

The input energy from various plant protection chemicals (PPCs) revealed notable differences between the direct seeded rice (DSR) and conventional puddled transplanted rice (PTR) methods. Specifically, the energy inputs from rodenticides, insecticides, and weedicides were recorded at 186 MJ/acre, 275 MJ/acre, and 328 MJ/acre, respectively, for DSR. In contrast, the corresponding values for PTR were significantly lower, at 60 MJ/acre for rodenticides, 227 MJ/acre for insecticides, and 122 MJ/acre for weedicides. This indicates that farmers utilizing DSR derived approximately three times more energy from rodenticides and 2.5 times more from weedicides compared to their PTR counterparts. Additionally, the energy derived from insecticide use was about 21% higher in DSR than in PTR. Furthermore, the energy consumption associated with electricity for irrigation was markedly higher in the PTR method, totaling 8,654 MJ/acre compared to 7,278 MJ/acre in DSR, reflecting an increase of 1,376 KWh. Similar studies have highlighted the indiscriminate use of nitrogen fertilizers and irrigation water, which accounted for approximately 36% and 39% of the total energy input in transplanted paddy systems, respectively (Chaudhary *et al.*, 2017; Basavalingaiah *et al.*, 2020). These findings highlight the critical differences in energy utilization between the two cultivation methods, particularly in relation to chemical inputs and irrigation practices.

Energy consumption on direct seeded rice (DSR) farms was approximately 11% lower than that on conventional puddled transplanted rice (PTR) farms. The findings indicate that the input energy from fertilizers and electricity used for irrigation were the primary energy sinks in paddy cultivation. Consequently, effective management of fertilizers—particularly nitrogen—and optimizing electricity use for irrigation are critical areas for enhancing energy use efficiency. By implementing need-based fertilizer recommendations and adopting DSR practices, it is possible to substantially reduce energy consumption in paddy production, translating into direct energy savings while maintaining productivity levels. Similar results were observed in a study conducted in Iraq, which highlighted differences in energy inputs between DSR and PTR systems, specifically regarding diesel fuel, pesticides, electricity, irrigation, human labour, and total input energy. The study found that the energy input for DSR was lower than that for PTR, resulting in a higher energy use efficiency (EUE). This suggests that DSR can significantly improve energy efficiency and sustainability in rice production (Eskandari and Attar, 2015).

The comparative analysis of input and output energy in direct seeded rice (DSR) and conventional puddled transplanted rice (PTR) cultivation revealed that both input and output energy levels were lower on DSR farms compared to PTR farms. However, the net energy gain for DSR was higher, with values of 65,722.57 MJ/acre for DSR compared to 63,634.26 MJ/acre for PTR. A study conducted in Bangladesh revealed that increased energy input does not necessarily correlate with higher energy gains. This highlights the importance of implementing environmentally sound management practices to achieve sustainable rice production (Rahman *et al.*, 2015). Such practices are essential for optimizing energy use while maintaining agricultural productivity and minimizing environmental impact.

The energy intensity was notably lower in direct seeded rice (DSR) cultivation, measured at 7.84 MJ/kg, compared to 8.86 MJ/kg for conventional puddled transplanted rice (PTR). This indicates that DSR farms are relatively more energy efficient than PTR farms in terms of energy productivity. The higher energy intensity of 8.86 MJ/kg in PTR highlights significant potential for improving energy productivity in traditional transplanting methods. Addressing this inefficiency could lead to enhanced sustainability and productivity in rice cultivation.

Comparative cost structure of input use in paddy cultivation: DSR vs. PTR method

In this study, the cost structure of energy use pertains to the actual expenses incurred by farmers for producing one acre of paddy on both direct seeded rice (DSR) and conventional puddled transplanted rice (PTR) farms, as presented in Table 4. The results indicate that the total variable cost associated with energy use was approximately 15.65% lower on DSR farms, amounting to Rs 23,344.06 per acre, compared to Rs 27,677.33 per acre on PTR farms. This significant reduction in costs highlights the economic advantages of adopting DSR practices in paddy cultivation.

The comparison of different inputs used in direct seeded rice (DSR) and conventional puddled transplanted rice (PTR) revealed that labour costs were approximately 41% higher in PTR compared to DSR. Additionally, the input costs associated with draught animals, machinery, chemical fertilizers (urea, phosphatic fertilizers, and MOP), zinc, electricity for irrigation, and farmyard manure (FYM) were nearly double in the PTR method. Specifically, the cost shares for these inputs were higher by about 25%, 10%, 30%, 21%, 6%, and 18%, respectively, when comparing PTR to DSR. On the other hand, higher seed costs were observed in DSR due to the greater seed rate and the use of more expensive short-duration varieties, as opposed to the long-duration, lower-cost varieties

Table 4. Cost (Rs./ acre) of different inputs used in paddy cultivation by DSR and PTR methods in Punjab (2021-22)

Sr. No.	Input/Method	DSR	PTR	Mean difference	% change over PTR
1	Human Labour	5354.82 (22.94)	9004.70 (32.53)	-3649.88	-40.53
2	Animal Labour	262.50 (1.12)	350.00 (1.26)	-87.50	-25.00
3	Machine Labour#	3259.48 (13.96)	4106.20 (14.84)	-367.50	-9.87
4	Combine Harvesting	1500.00 (6.43)	1500.00 (5.42)	0.00	0.00
5	Seed	681.20 (2.92)	394.50 (1.43)	417.69	105.88
6	Fertilizers and micro nutrients				
a	Urea	852.76 (3.65)	1011.78 (3.66)	-159.02	-15.72
b	Phosphatic	156.96 (0.67)	163.20 (0.59)	-6.24	-3.82
c	Muriate of Potash	128.94 (0.55)	142.80 (0.52)	-13.86	-9.71
d	Zinc	282.28 (1.21)	357.50 (1.29)	-75.22	-21.04
e	Iron Sulphate	146.95 (0.63)	138.00 (0.50)	8.95	6.49
f	Others##	348.0 (1.49)	324.00 (1.17)	57.68	17.80
7	FYM (Tonne)	1148.30 (4.92)	1180.00 (4.26)	-31.7	-2.69
8	Plant Protection Chemicals	3946.27 (16.90)	2735.00 (9.88)	1211.27	44.29
9	Electricity for irrigation	4270.35 (18.29)	5077.80 (18.35)	-807.45	-15.90
10	Interest on variable cost @ 9 per cent p.a. for half the period of crop season	1005.25 (4.31)	1191.85 (4.31)	-186.6	-15.65
11	Total Variable Cost	23344.06 (100.00)	27677.33 (100.00)	-4333.27	-15.65

Figures in the brackets indicate the percentage to total variable cost
does not include diesel use for harvesting the crop and transport on farm
includes seed treatment chemicals and growth regulators

typically used in PTR. Furthermore, DSR adopters incurred approximately 6% more in expenditures on iron sulfate and 18% more overall on other inputs. This cost analysis highlights the economic differences between the two cultivation methods and suggests potential areas for optimizing input use in paddy production.

In the total variable costs associated with input energy in paddy cultivation, the largest share was attributed to human labour, comprising approximately 23% for direct seeded rice (DSR) and about 33% for conventional puddled transplanted rice (PTR), reflecting higher labour requirements in the latter. Machine labour, utilized across various cultural practices and harvesting, along with diesel fuel, accounted for roughly 20% of the total variable cost in both cultivation methods. Additionally, electricity used for irrigation represented about 19% of the total variable costs involved in paddy cultivation. The costs for fertilizers and micronutrients were marginally higher in DSR (13%) compared to PTR (12%). Moreover, plant protection chemicals were approximately 7% more expensive in DSR (16.9%) than in PTR (9.88%). The share of seed costs was nearly double for DSR (2.92%) compared to PTR (1.43%). This breakdown of costs highlights the key areas influencing the economic viability of each cultivation method.

The results concerning key economic parameters—

Table 5. Economic benefits of DSR paddy cultivation (2021-22)

Sr. No.	Particulars	DSR	PTR	Advantage in DSR (%)
1	Yield (kg/acre)	2769.00	2801.30	-1.15
2	Total variable cost(Rs/acre)	23344.06	27677.33	-15.66
3	Gross returns (Rs/acre)	54826.20	55465.74	-1.15
4	Net returns over variable cost (Rs/acre)	31482.14	27788.41	13.29
5	Cost of Grain production (Rs per kg)	8.43	9.88	-14.67
6	Energy (MJ per kg)	7.84	8.86	-11.50

such as yield, total variable cost, gross returns, and net income—comparing direct seeded rice (DSR) to conventional puddled transplanted rice (PTR) are summarized in Table 5. These parameters are crucial for evaluating the economic performance of each cultivation method, providing insights into their viability and sustainability in paddy production.

The results indicated that although the yield in direct seeded rice (DSR) cultivation (2,769 kg per acre) was marginally lower than that of conventional puddled transplanted rice (PTR) (2,801.3 kg per acre), the net returns over variable costs were approximately 13% higher in DSR, amounting to Rs 31,482.14 per acre compared to Rs 27,788.41 per acre for PTR. This increase in net returns can be attributed to the lower variable costs associated with DSR. Additionally, the cost of producing one kilogram of grain using DSR was found to be lower, at Rs 8.43 per kg, which is about 15% less than the cost in PTR, which was Rs 9.88 per kg. Furthermore, the input energy required for DSR was 7.84 MJ per kg, compared to 8.86 MJ per kg for PTR. These findings highlight the economic advantages of adopting DSR despite the slightly lower yield.

Thus, the results of the present study indicate that direct seeded rice (DSR) is a more input- and cost-efficient technology for paddy cultivation compared to the traditional puddled transplanted rice (PTR) method. This finding highlights the potential of DSR to enhance economic sustainability in rice production while reducing overall resource use.

CONCLUSION

Direct seeded rice (DSR) technology has the potential to enhance farmers' income and conserve valuable resources. While DSR offers a viable alternative to address challenges such as rising cultivation costs, labour shortages, and water scarcity for sustainable rice production, its adoption in the state has not yet reached a significant scale. To promote DSR practices effectively, there is a pressing need to increase awareness among farmers regarding recommended production practices and their associated benefits. Various stakeholders, including government agencies, agricultural organizations, and NGOs, can play a crucial role in disseminating information about DSR. Developing educational materials, such as success stories in print, audio, and video formats, and distributing them through both traditional and Information and Communication Technology (ICT) channels will be advantageous. The study highlights the importance of extension interventions aimed at promoting efficient management practices for insect-pests, and weeds, as well as enhancing farmers' skills through training programs. Additionally, farmer cooperatives and community-based organizations can be mobilized to facilitate awareness through peer learning, farmer field schools, and knowledge-sharing platforms. Government initiatives, such as subsidizing the costs associated with DSR cultivation per acre, could further encourage its adoption, potentially expanding the area under DSR. Furthermore, more research is needed to develop high-yielding rice varieties with desirable traits, including vigorous growth, weed suppression capabilities, and tolerance to micronutrient deficiencies, which are suitable for DSR cultivation.

Authors' contribution

Conceptualization and designing of the research work (SR); Execution of field/lab experimentsand data collection (GS); Analysis of data and interpretation (SR); Preparation of manuscript (GS).

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