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Factors affecting farmers' acceptance and adoption of Direct seeded rice technology in developing climate resilience among Rice farmers in Odisha, India.

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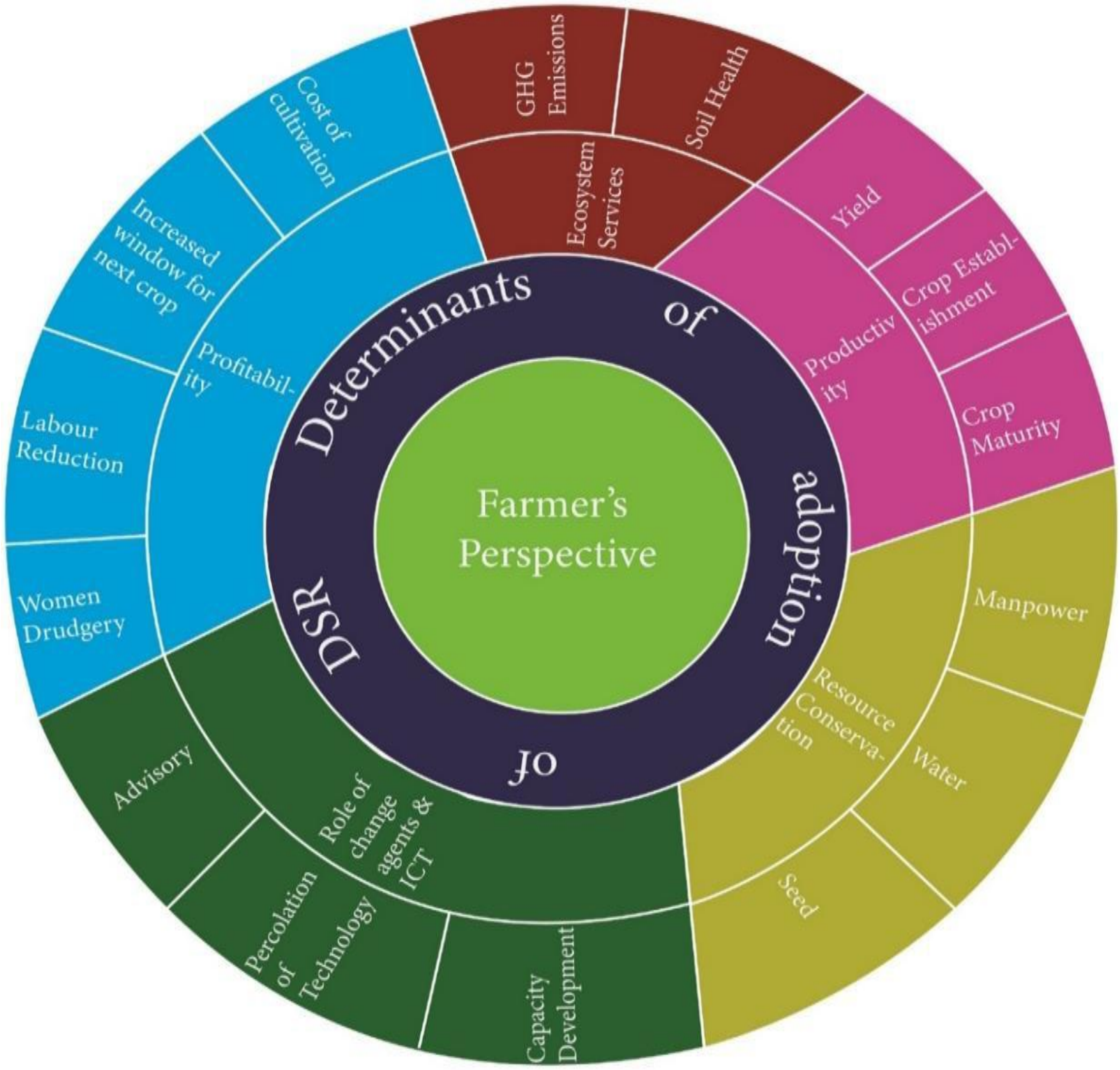
Graphical Abstract



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Abstract

The study examines the adoption of Direct-Seeded Rice (DSR) technology in Odisha, where rice farming primarily relies on resource-intensive transplanted rice (TPR) practices. DSR offers advantages in water usage, labor, energy, emissions, and cost savings, but its adoption among farmers remains limited. The research aims to understand traditional practices, farmers' attitudes, and the constraints affecting DSR adoption in Odisha's Khorda and Puri districts. A structured questionnaire was dispensed to 120 farmers practicing both DSR and TPR. The data was assessed using descriptive statistics, Principal Component Analysis (PCA), Likerts, and Mann Whitney U test. Findings indicated that key constraints for DSR adoption include the unavailability of skilled labor, soil problems and weed issues. Economic analysis reveals that the cost of TPR production is 16.3% higher than DSR, and DSR exhibits a better benefit-to-cost ratio. The study suggests that resource conservation, productivity improvement, economic profitability, and environmental concerns drive farmers to practice DSR. Results of PCA suggest that it is possible to significantly increase DSR acceptance among the control group by utilising ICT technologies and extension agents. The study concludes that increasing DSR adoption requires the development of more suitable rice varieties, improved weed management strategies, and capacity building for farmers. Embracing DSR can address challenges faced by Odisha farmers, contributing to achieving food security and mitigating the impacts of climate change. This paper also serves as an important baseline for the implementation of further large-scale projects on DSR adoption.

Keywords: Direct seeded rice (DSR); Farmer's perspective; Principal Component Analysis (PCA); Puddled rice; Resource Conservation Technology (RCT); Rice crop manager (RCM); Transplanted Rice (TPR).

1. Introduction

India holds second position in rice production after China (GRiSP 2013). Having a historical yield of 122 Mt between 2020 and 2021, India has the biggest area dedicated to rice farming at 44.4 Mha (USDA 2021). As a staple food, rice is vital to both India's food security and economic development. According to Mohanty and Yamano (2017), more than one-fourth of the calorie intake comes from rice. Eastern part of India has fallen behind the rest of the country in terms of rice production as well as farmer wealth (Jha et al. 2012). This can be attributed to obstacles such as flooding, drought, salinity levels, and poor fertility of soil, with incorrect or inadequate fertiliser application (Singh and Singh 2000).

In Odisha, agriculture and rice are both equated with food. About 69% of the land is cultivated for rice, which accounts for 63% of the land that is used to grow food. One of the largest producers of rice in eastern India is Odisha (Dar et al. 2017). Odisha produces a large portion of its rice on sparsely populated tiny plots of land with different crop management techniques and restrictions. Because of this, rice directly affects the economy of the state, availability of food, nutritional status, and efforts to reduce poverty.

Approximately 77% of the rice in India is planted using the manual transplantation in puddled soil (TPR) method (Rao et al. 2007). In the past, farmers had been encouraged to utilise this technique owing to the readily available irrigation water and the low cost of labour. The sustainability and feasibility of the TPR system are, however, being threatened as these resources become more expensive and scarcer. The difficulties with TPR have been extensively studied by researchers. These difficulties include the higher yield disparity (Lobell et al. 2009), diminished water and nutrient productivity (Sudhir-Yadav et al. 2011; Humphreys et al. 2010), higher greenhouse gas (GHG) emissions (Chaudhary et al. 2022), restricted energy use efficiency (Quilty et al. 2014), declining labour supply (Chaudhary et al. 2022), and associated spikes in renumeration (Sudhir-Yadav et al. 2017; Bandumula et al. 2018) and elevated women's drudgery (Akter et al. 2017), that increase cultivation costs and decrease profitability (Ditzler et al. 2018).

Compared to TPR, direct seeded rice (DSR) promotes mechanization which helps to decrease women's labour, workforce, production expenses, and the energy use (Kumar and Ladha 2011; Gathala et al. 2014; Laik et al. 2014) while preserving as much as 30% of the total cost of production (Alam et al. 2018), between 30 and 50% of the water used for irrigation, and other resources (Sudhir-Yadav et al. 2011a,b; Chaudhary et al. 2022). Additionally, DSR lowers tillage, prevents puddling-related soil structure loss, and lessens the need for labour while enabling prompt establishment of crop (Kumar and Ladha 2011). Farmers are gradually switching from the TPR system to the DSR system for all these great reasons (CSISA 2017). In China, a comparable shift to the wet technique for direct seeded rice (Wet-DSR) has been recorded by Wang et al. 2017. Also, farmers' perceptions of water as freely available and abundant resource must change (Kumar and Batra 2017).

As an alternative sustainable intensification technology, dry-direct seeded rice (Dry-DSR) and machine transplanted rice (MTR) have undergone considerable evaluation and promotion in Odisha. It is carried out to tackle the challenge of the depleting natural resources, particularly water, and the developing labour shortage (CSISA 2017). If done with adequate weed control and water management techniques, direct seeded rice can boost yield, decrease fertiliser and field preparation costs, raise household income, and improve land productivity (Mishra et al. 2017).

In Odisha, majority of the farmers practice bueshening. The chances of pest and disease attack are more in this practice. Though they have this kind of mindset, it will be easier to convince them for DSR practice through mechanisation.

The current study's objectives were to: -

i. Take into account farmer's perspective on adopting DSR practice.
ii. Contribution of Information and communication technology (ICT) and change agents' in advancing and expanding DSR.

Knowing and comprehending farmers' perspectives has traditionally been crucial before scaling up any climate-resilient practises or any new technology for that matter because it influences the decision making and adoption of any practice. But determining the mindset of farmers can be a complex task that involves analyzing various parameters. The parameters that I undertook in my study are- socio- economic factors, education and training, cost of production, climate and weather, government policies, market access, role of change agents, ICT and advisory, impact of Covid, role of women in decision making etc. are to name a few. The mechanics of the expansion and ramping up process can be profoundly affected by an improved understanding of the DSR adoption drivers and determinants. Comparatively speaking to other districts in the state, Odisha's coastal regions produce more agricultural goods. These regions contribute significantly to the state's economy. With this consideration, the study was done in Odisha's Puri and Khordha districts. This is the first of its kind work to identify practical challenges on DSR, as there are very limited studies especially for eastern India.

This study sheds light on the factors that influence DSR adoption and explains the variation in DSR adoption levels between households. This study employs a bottom-to-top methodology in an effort to better understand and address the obstacles to DSR adoption as well as develop a more effective business model among farmers, researchers, extension specialists, policymakers, and other private sector stakeholders for developing and promoting cutting-edge DSR technologies. This paper also serves as an important baseline for implementation of further large-scale projects on DSR adoption.

2. Materials and methods

2.1 Study area and site characteristics

Given variations in agro-ecology, socio-economics, density of residents, and intensity of cropping, this study was completed in Odisha's Puri and Khordha districts (East and South Eastern Coastal Plain). (Fig. 1). For Odisha, cropping intensity of 113.800 hath was recorded in 2020. Odisha lies between the longitudes of 81°27' and 87°29'E and the latitudes of 17°49' and 22°34'N. The Odisha state's coastal district of Puri is located in latitudes 19° and 84°29'E. It covers a land area of 3051 km^2. Agriculture, which includes the cultivation of commodities including paddy, lentils, and vegetables, is the district's primary revenue generator. An administrative division of the state is the Khordha district. It is located at latitudes 20.11° N and longitudes 85.40° E. The area of the district is 2,888 km^2. The district is home to the state capital, Bhubaneswar, and is an important center for education, healthcare, and IT industries. Agriculture is also a significant economic activity in the district, with crops like paddy, oilseeds, and vegetables being grown. The population density in the Khordha and Puri districts is 488 and 800 people per km2, respectively. Additionally, from 2001 to 2011, the literacy rates in the districts of Khordha and Puri were 76.05 and 86.88, respectively.

With average annual rainfall of 1577 mm, and the mean peak summer temperature of 39°C and the mean lowest winter temperature of 11.5°C, the region's climate is marked by humid and hot summers and chilly winters. The research area's climate is classified as tropical monsoon type. The southwest monsoon arrives around early June and leaves around mid-October. During the monsoon season, which begins on 1 June and lasts until 15 October, 80% of the annual rainfall is recorded. The remaining sum is received during the year.

In terms of water availability, both Puri and Khorda districts are located along the coast and have access to seawater. However, the districts rely mainly on groundwater for their water needs. In recent years, there has been a decline in the water table in both districts due to overexploitation of groundwater resources. The state government has taken steps to address this issue by promoting rainwater harvesting and groundwater recharge, among other measures. In addition, the Mahanadi river, which flows through Khorda district, is an important source of water for irrigation and other purposes. However, the river has been affected by pollution and overuse, which has led to water scarcity in some areas.

Kharif is the main harvest season and rice is the principal crop. During the rabi season, farming is mostly restricted to irrigated and moist areas. Frequent cyclones are common in this region.

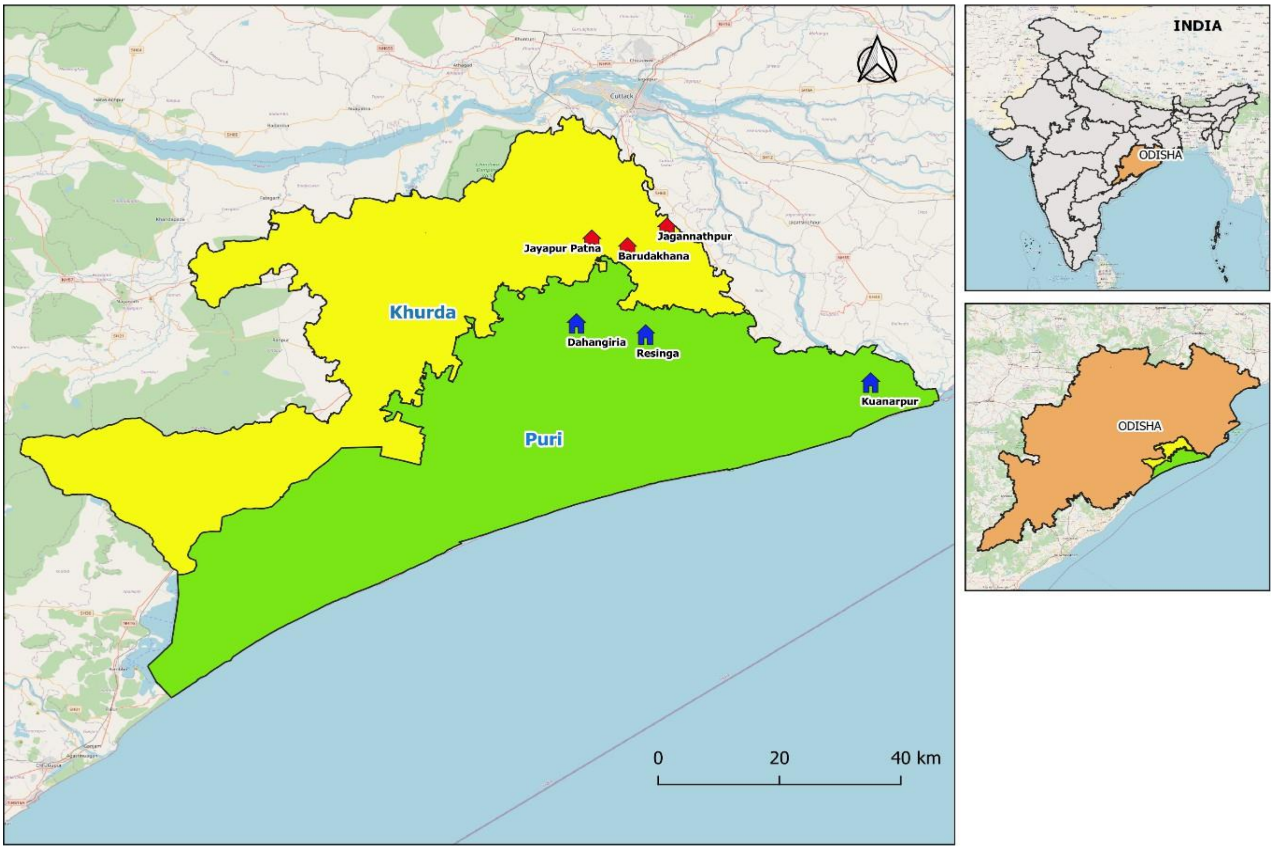

Fig. 1 Map of study area showing the Puri and Khorda district with sampling sites

2.2 Sampling procedure and collecting data

Following a preliminary survey, data were mostly collected using key informant interviews and a multi-stage structured questionnaire-based survey to households. The comments from the key informant interviews obtained during the preliminary survey served as the basis for the questionnaire design. To collect quantitative data from the sampled respondents, the organized survey comprised open-ended as well as closed-ended inquiries. The survey was used to gather data from the participants in the study on aspects related to changing climates, weed and pest management, irrigation, crop yields, and marketing. It also sought information on the respondents' livelihoods, livestock, and the condition of the soil. It also attempted to understand their motivations for adopting DSR and their challenges. Prior to the questionnaire's final field observation, it was pre-tested on five households and crucial informants. To fill up the blanks in the survey and to confirm the findings, key informant interviews were done. The study included a vast spectrum of participants, including landowners, important village and ward heads and officials, district administrators and officials, and non-profit members that work in the study areas.

2.3 Sampling and analysis Plan

The research was carried out in 3 villages (Resinga, Danagahir, Kuanarpur) of Puri and 3 villages (Jayapurpatana, Barudakhana, Jaganathpur) of Khordha district that adopted DSR based management practices. Ten farmers from each village who adopted DSR and ten from the control group (who followed TPR) were picked at random, for a total of 120 farmers. Canal and bore wells are the major source of irrigation in these villages.

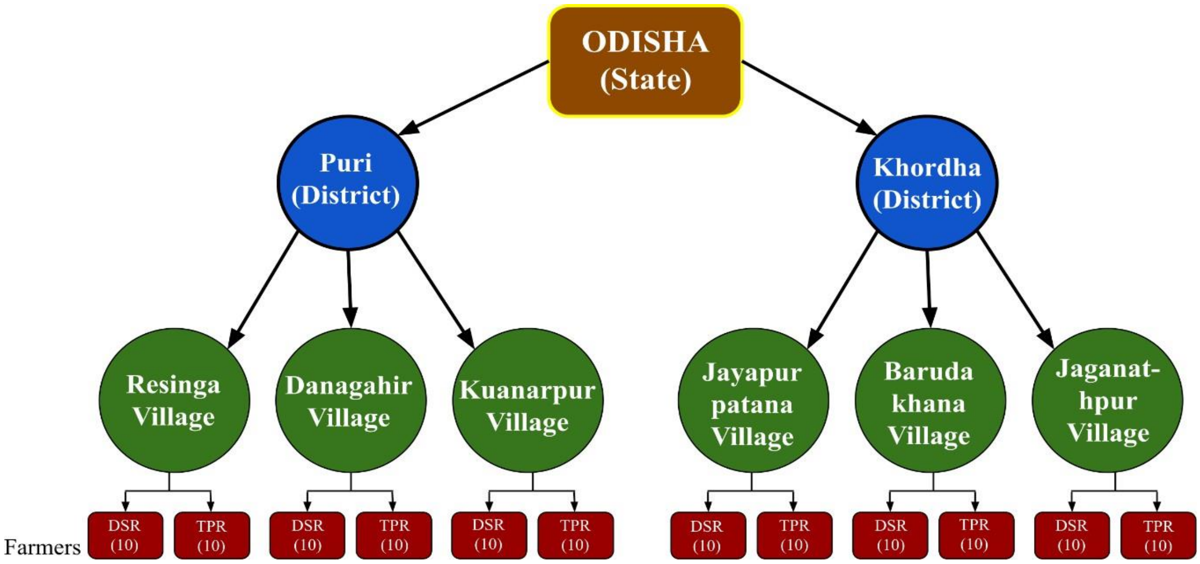

Fig. 2 Simplified sampling plan of the survey

A household survey employing an interview format was used to gather primary dataset. Coding and computer entry were done with the raw data that was collected. Microsoft Excel and the statistics Package for Social Sciences (SPSS statistics package. 19) were used for the final analysis after the local measurements had been changed into standard units. The socio-economic traits of the farmers were examined using descriptive statistics such as mean, percentage, and deviation from the mean.

The respondents were informed in advance of the study's goal. Respondents were further reassured that their names would not be shared and that the data we obtained would only be used for academic research. The native language of the area, Oriya, was used for both the questionnaires and the interviews. Following the completion of the survey, the collected data were translated into English.

2.4 Statistical Analysis

The adoption-influencing factors were discovered using descriptive analysis. Data from the questionnaire survey was synthesised for each agronomic parameter from each group using the SPSS statistical package19. Xlstat was used to perform the Mann Whitney U test, the Principal Component Analysis (PCA), and data visualisation. It was utilised to pinpoint the crucial factors impacting the uptake and expansion of DSR. All original variables were converted into a more manageable linear combination known as principle components (PC) in order to perform PCA. For some of the questionnaire answers, a Likert scale with five possible responses—strongly disagree (1) to strongly agree (5)—was used.

2.5 Calculating the production post

By adding costs of all the variable inputs and opportunity costs, the overall cost of production was computed. Variable costs include the costs of seed, labour, fertiliser, farmyard manure (FYM), machinery, and irrigation, whereas opportunity costs include the costs of paying rent for the land and using one's own tools. Total cost is the result of adding opportunity cost and total variable cost.

Calculating the returns: For both DSR and TPR, the gross return, net return and Benefit to Cost ratios were determined using the method and formulas that were employed by Sapkota and Sapkota (2019).

Gross Return

The sum of the returns on grain and straw was used to calculate the gross return.

Gross return = grain return + straw return

Grain return was computed by multiplying the average grain production in tonnes by the price per tonne. Similarly, the straw yield was also calculated.

Grain return = Average grain produced (tonnes) x price per tonne

Straw return = Average straw produced (tonnes) x price per tonne

The minimum support price (MSP), set by the Indian government, for rice was INR 1815 (Rs per quintal). For Odisha, the straw was priced at Rs. 1.5 per kg (Odisha University of Agriculture & Technology, Bhubaneswar, Odisha).

Net return

The difference between gross return and total production costs was used to compute net return.

Net return = Gross return – total cost

Benefit-Cost (B: C) Analysis

Benefit to Cost Ratio (BCR) measures the relationship between the total cost expended and the gross return.

B: C ratio = gross return / total cost

3. Results and Discussions

3.1 Statistics on household and farm characteristics

Table 1 shows a profile of respondents who took part in the questionnaire-based survey. Gender, age, education, financial status, number of family members and total land holding were among the studied socio-economic factors. The majority of households were headed by men, with 67% of household heads being men and 33% being women. This suggests that the majority of rice farmers are men. The bulk of rice farmers (82.5%) were in the 35–55 age range. Only 10% of household heads had a degree, while 16% had only a primary education. Low literacy rates might have a negative effect on rice output. Nwele (2016) also discussed how education could impact the farmer's decision-making process, such as adopting new farm innovations and technologies. Better education can definitely help farmers deal with traders in a better way.

Table 1 Basic description and summary of respondents

Description		DSR		TPR		Total	
		No. of farmers	% of farmers	No. of farmers	% of farmers	No. of farmers	% of farmers
Total no. of farmers surveyed		60		60		120	
Sex	**Males**	36	60%	44	73%	80	67%
	Females	24	40%	16	27%	40	33%
Age	**<35**	4	7%	2	3%	6	5%
	35-45	36	60%	24	40%	60	50%
	46-55	12	20%	27	45%	39	33%
	>55	8	13%	7	12%	15	12%
Total land holding (ha)	**Marginal (Less than 1)**	28	47%	33	55%	61	51%
	Small (In between 1-2)	31	52%	26	43%	57	48%
	Small-medium (In between 2-4)	1	2%	1	2%	2	2%
Education	**primary**	10	17%	9	15%	19	16%
	Secondary	34	57%	36	60%	70	58%
	Higher secondary	11	18%	8	13%	19	16%

	Graduate	5	8%	7	12%	12	10%
Financial status	**Below poverty line**	5	8%	0	0%	5	4%
	Lower middle class	33	55%	27	45%	60	50%
	Upper middle class	22	37%	33	55%	55	46%
	High income group	0	0%	0	0%	0	0%

The majority (95.8%) of farmers belonged to the middle class. Fifty-one percent of farmers had marginal land holding (less than 1ha of land). The size class reference was taken according to the Agri-census 2015-16. The percentage distribution of operational holdings as per the five broad size groups reveals that the marginal category of holdings has been steadily increasing. Both marginal and small holdings account for 98% of the total holdings in the survey leaving a balance of 2% for semi-medium. This may be attributed to the population growth and fragmentation of holdings due to emerging of the nuclear family system. Evidences from previous studies have reflected that the choice to embrace any new technology is influenced by variables including size, income, and workforce of the farm (Mishra et al. 2022). Therefore, it is believed that social structure and demographic traits are rather pertinent to the adoption decision. The mean farm size for the entire sample in DSR is 2.62 acres, but it is 2.56 acres for TPR. Small landowners are thought to be less willing to take risks than large-scale farmers since they have less money to invest in new machinery (Ngwira et al. 2014). Only 13% of the sample households in TPR and 20% of those in DSR have larger families (>5 adults), which is an essential requirement for accepting the risk of a recently discovered innovation. Farmers are compelled to find a new source of income by such circumstances.

The Tropical Livestock Unit (TLU) was calculated for each family. The average TLU in DSR and TPR were 2.885 and 1.415, respectively. An increase in the number of animals per adult that are available to assist the family is a sign that food security and household resilience have improved. As a result, any relative change in the TLU serves as a clear indication of the risk to food security.

About 48% of farmers inspect soil periodically in DSR practice. However, only 22% of the control group members are aware of soil health and soil examination. Such outcomes also have a sizable role in the decreased adoption rate of DSR.

3.2 Crop Information

Paddy was the primary crop grown in Kharif season while in Rabi, DSR practitioners mostly grew pulses (a few grew groundnut) while mixed practice was observed in the control group. Some grew paddy where irrigation water was available, some grew pulses, some groundnut, a few grew black gram, and some left the land fallow. In DSR, the most grown variety was found to be SwarnaSub1 followed by Bina11 and Swarna. In TPR, the most grown variety was found to be Bina11 followed by Lalat and SawarnaSub1. The varieties used are mainly medium to long duration varieties. Respondent farmers in DSR utilized a range of seed rate (12-20 kg ha^{-1}), with an overall average of 18.02 kg ha^{-1}. This demonstrates that each farmer practices DSR in his or her unique method. In this case, seeding equipment like happy seeder can be advantageous.

In DSR, an overall grain yield was 5.4 t/ha, whereas in TPR it was 5.7 t/ha. Smaller land holdings, disregard for the ideal time to start farming, and ineffective utilization of rainwater are only a few of the factors cited in the survey as contributing to the current output gap in DSR. The average straw yield in DSR was 9.4 t/ha and 9.6 t/ha in TPR. When the respondents were asked about the fate of straw, it was found that 88% of farmers leave it in the field (retention), and 43% remove it for thatching, mushroom cultivation, or use in cow dung cakes. A few respondents (15%) said that they burn it because of labor shortages or to prepare their land for succeeding crop. Similarly, in the control group, 72% of respondents retained the straw residues in the field and 52% removed them and 7% burnt it. When asked whether the respondents knew about the detrimental effects of straw burning, only a few knew about pollution and climate change that takes place due to crop residue burning and its effects on soil health. According to the survey, the significant weeds observed in DSR plots were Barnyardgrass (Echinochloa crus-galli), Broadleaf signalgrass, Yellow nutsedge. In some plots, Sprangletop was also observed. In TPR, major weed observed was Broadleaf signalgrass. Other weeds were also observed but they were not very prominent. As most of the farmers has marginal and small landholdings, they used a manual method of weeding. A few farmers used chemical methods also to control weeds in TPR, but it was opposite in DSR. Most farmers used chemical methods to control weeds along with manual weeding. They used Pendimethalin and Nominee Gold (Bispyribac Sodium 10% SC) as weedicides. TPR farmers mostly used Pendimethalin.

Farmers used both chemical and organic fertilizers (compost). The rate of fertilizer applied by the farmers in DSR followed the RCM recommendations, whereas in TPR it was the farmer fertilizer practice. Approximately, all farmers (around 97%) used all N, P, and K fertilisers, urea fertilizer as basal, muriate of potash fertilizer and diammonium phosphate as topdressing. Compost was also added in both systems, but its quantity was higher in DSR to compensate for the lower urea levels in the basal dose. Most of the farmers used chemical pesticides to control pests and diseases. A few respondents also practiced integrated pest management practices like sticky yellow cards. It was found that farmers were familiar with the terms ‘organic farming’ and ‘conservation agriculture’ but no one practiced it.

The Mann Whitney U test was administered, in order to determine the statistical significance of several characteristics (Table 2). The variety used for DSR and TPR in Kharif was found to be entirely different. Hence it is statistically significant. The second parameter was the duration of variety used. The preference for duration is not a factor in comparing both practices. It is evident from the table that retention of the straw in the field is more significant in DSR than TPR, so farmers prefer it, but the removal and burning do not depend on the type of practice and are entirely on the choice. In DSR, weeds were more but in TPR Broadleaf signalgrass was present significantly. Irrespective of the practice, farmers prefer both manual and chemical methods to control weeds. However, the manual is highly significant in TPR and the chemical is highly significant in DSR.

Table 2 Mann Whitney U test for some parameters (Variety used in DSR and TPR; Duration of variety used; Fate of straw; Common weeds; Method of weed removal); Total number of treatments=120 for all parameters

	Treatment	Mean Rank	Sum of Ranks
Variety used in Kharif	DSR	47.69	2861.50
	TPR	73.31	4398.50
Short duration	DSR	30.50	1830.00
	TPR	90.50	5430.00
Medium duration	DSR	67.50	4050.00
	TPR	53.50	3210.00
Long duration	DSR	69.50	4170.00
	TPR	51.50	3090.00
Straw Retention in the field	DSR	65.50	3930.00
	TPR	55.50	3330.00
Burn	DSR	62.70	3762.00
	TPR	58.30	3498.00
Remove	DSR	58.00	3480.00
	TPR	63.00	3780.00
Barnyardgrass (Echinochloacrusgalli)	DSR	83.00	4980.00
	TPR	38.00	2280.00
Broadleaf signalgrass	DSR	62.00	3720.00
	TPR	59.00	3540.00
Yellow Nutsedge	DSR	83.50	5010.00
	TPR	37.50	2250.00
Sprangletop	DSR	65.50	3930.00
	TPR	55.50	3330.00
Weed Removal (Manual)	DSR	40.00	2400.00
	TPR	81.00	4860.00
Weed Removal (Chemical)	DSR	85.50	5130.00
	TPR	35.50	2130.00

3.3 Cost of production

As economics/ cost of production plays an integral role in acceptance of any novel technology, it's one of the key parameters. Table 3 shows the overall economic production expenses for DSR and TPR. The aggregate economic value of producing per hectare of transplanted rice and direct seeded rice is INR 69875 and INR 58500, respectively, implying that the economic cost of production for TPR was 16.3% more than that of DSR. This extra price in TPR is due to higher land preparation costs, increased labour costs for nursery administration and seedling transplantation, and more seed and irrigation costs for constant flooding. According to the statistics in Table 3, DSR technology saves money on land preparation (31%), seed (50%) and sowing (80.6%), irrigation (20%), fertilisers (11.6%), and micronutrients (28.6%). In contrast, the expense of plant protection measures (weed and disease infestations) on DSR is higher than on transplanted rice crop. Sapkota et al. (2019), Latif et al. (2017), and Younas et al. (2016), all reported similar findings.

Table 3 Comparing the cost of production in DSR and TPR and savings through the adoption of DSR

Cost of production of DSR and TPR crop						
Sl. No.	Detail of cost components			DSR (kharif) Cost/ha	TPR (kharif) Cost/ha	Savings in DSR (%)
	Factors	**DSR**	**TPR**			
1	Land Preparation			5150	7500	3DSR
2	Seed			1000	2000	50.0
3	Labour for Nursery preparation	N/A	2 Labour	0	1500	100
4	Labour for Transplanting/Sowing	DSR machine cost and one labour	12 Labour	1750	9000	80.6
5	Irrigation	Rain	Rain + Irrigation	5000	6250	20.0
6	Fertilizer			4750	5375	11.6
7	Farmyard manure	two tractor trip	two tractor trip	7500	7500	0
8	Micronutrients (Zn/Boron etc.)	Zinc	ZINC	1250	1750	28.6
9	Plant protection Measures(weeds, insects, pests and disease control)	pendimethalin 30 ec and nominee gold		2500	1250	-100
10	Manual Harvesting and threshing	22 labour for Cutting and binding,threshing	22 labour for Cutting and binding,threshing	16500	16500	0
11	Land rent for one season	10bag paddy /acre if not Rs.5000	10bag paddy /acre if not Rs.5000	12500	12500	0
Total economic cost of production				**58500**	**69875**	**16.3**

Calculating the returns: Gross return, net return and Benefit-to-cost ratio (BCR) were computed for DSR and TPR which are presented in Table 4.

Gross return

Gross return for DSR and TPR were INR 112110 and INR 117855 respectively.

Net return

Net return for DSR and TPR were INR 53610 and INR 47980 respectively. Higher net returns indicate that DSR is viable and profitable as it saves on labour, seed and water.

Benefit-Cost (B: C) Analysis

BCR of the DSR and TPR methods came out to be 1.92 and 1.69 respectively meaning that growing rice with DSR technology was superior to transplanting. This study was analogous to the results of (Soriano et al. 2018; Kumar and Batra 2017; Latif et al. 2017; Younas et al. 2016), who found that the BCR of DSR was substantially higher than the conventional transplanted method.

Table 4 Average return (per ha) for DSR and TPR

Particulars	**DSR**	**TPR**
Average grain yield (tons/ha)	5.4	5.7
Price (Rs/ton)	18150	18150
Grain return (Rs/ha)	98010	103455
Average straw yield (tons/ha)	9.4	9.6
Price (Rs/ton)	1500	1500
Straw return (Rs/ha)	14100	14400
Gross return (Rs/ha)	112110	117855
Total cost	58500	69875
B:C ratio	1.92	1.69
Net return	53610	47980

3.4 Motivation for DSR adoption and expansion

Principal Component Analysis (PCA)

To examine how different variables varied and were linked to one another, a principal component analysis (PCA) test was conducted. Farmers' motivations for DSR were distilled into PCA components and variables on the basis of their experiences and opinions. The first main component (PC1), which emphasises the value of resources and economic viability, is substantially correlated with labour and water savings, cost of cultivation, GHG mitigation, and early maturity. At the same time, PC2 is strongly correlated to the weather forecast, agent of change, training and capacity development (TCD), and Information and communication tool (ICT), which is depicted in figure 3 as a bipolar plot. The principal component analysis was explained by PC1 and PC2 as 60.63% and 9.57%, respectively of the total variance. It can be concluded that resource conservation, productivity, and economic profitability, as well as environmental concerns, were driving forces for farmers practising DSR and using ICT tools and extension agents, may have a substantial part in increasing DSR adoption among the control group.

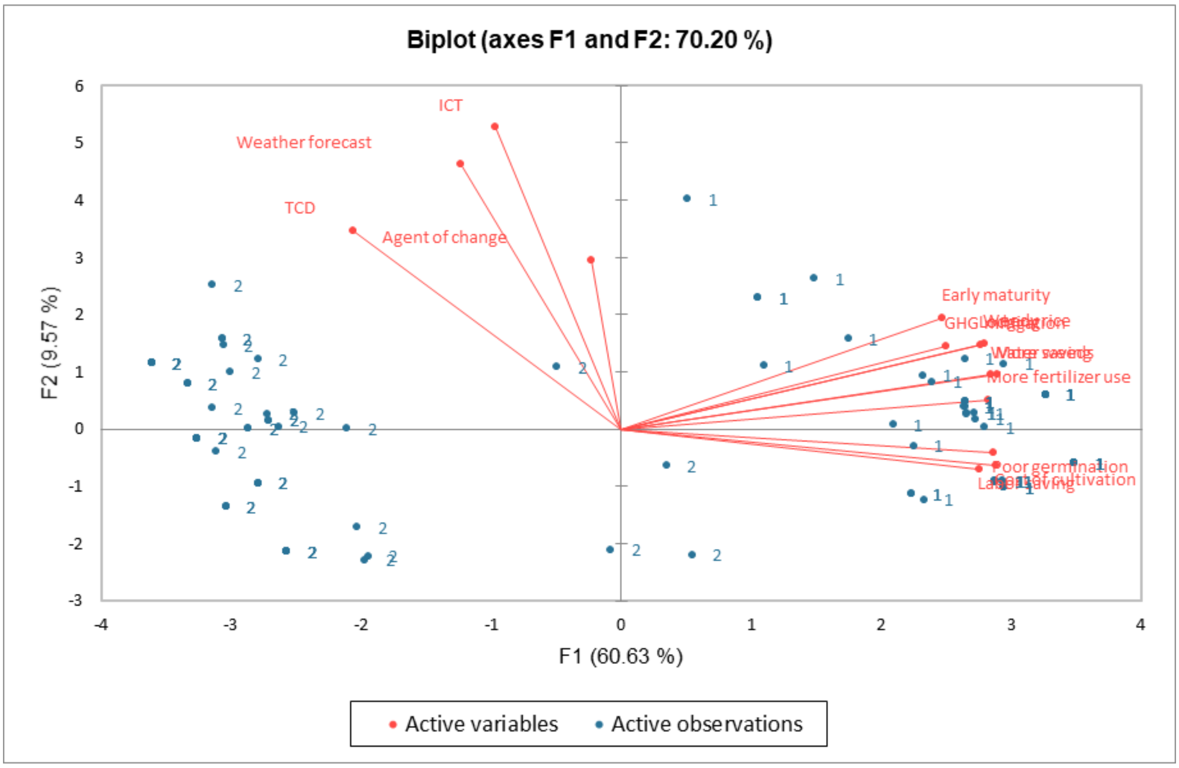

Fig. 3 Principal Component Analysis (PC1 and PC2) plot

3.5 Change agents' role and use of Information and Communication Technology (ICT) in dissemination and upscaling of DSR

Access to information is acknowledged by the diffusion of innovation model as the explicative component influencing adoption choices (Mishra et al. 2022). Farmers who have access to education and training tend to have a more positive mindset towards farming. Education and training help farmers understand the latest agricultural technologies, market trends, and best practices, which can improve their yields and income. Farmers value the function of DSR promoting agents and their important assistance in improving DSR practice and government subsidy programmes. Access to the input and support of change agents can help surmount the obstacles and restrictions of implementing DSR on a larger scale. Younas et al. (2016) reported comparable findings. Change agents, namely, the government extension agents, researchers, non-governmental organizations (NGOs), and the private ownership, undoubtedly play an important role in the transmission and acceleration of technological advances to farmers. This research attempts to determine the frequency of these agents' visits as well as their support/advice to farmers to improve DSR adoption and scaling up (fig. 4). It was observed that the frequency of visits was highest for private groups, followed by researchers and local agricultural departments. The change agents give farmers advise on a variety of topics, such as agronomic procedures, weather-related information, new government policies and upcoming trainings, market information, buyer information, diseases and pests, new DSR technologies, and livestock management. Small landowners are more reluctant to adopting decisions because they face a greater probability of failure owing to weather, market fluctuations, pests, and diseases. The top-down strategy, in which the extension agent sets DSR demonstrations in farmers' fields and expects them to adopt it, must be reversed. Instead, a more participative strategy in which farmers are empowered/made self-sufficient via the provision of supplies and guidance should be promoted. This will allow them to play around with the technology to figure out what works best for them and what adjustments are necessary to make it operate in their location (Mishra et al. 2022).

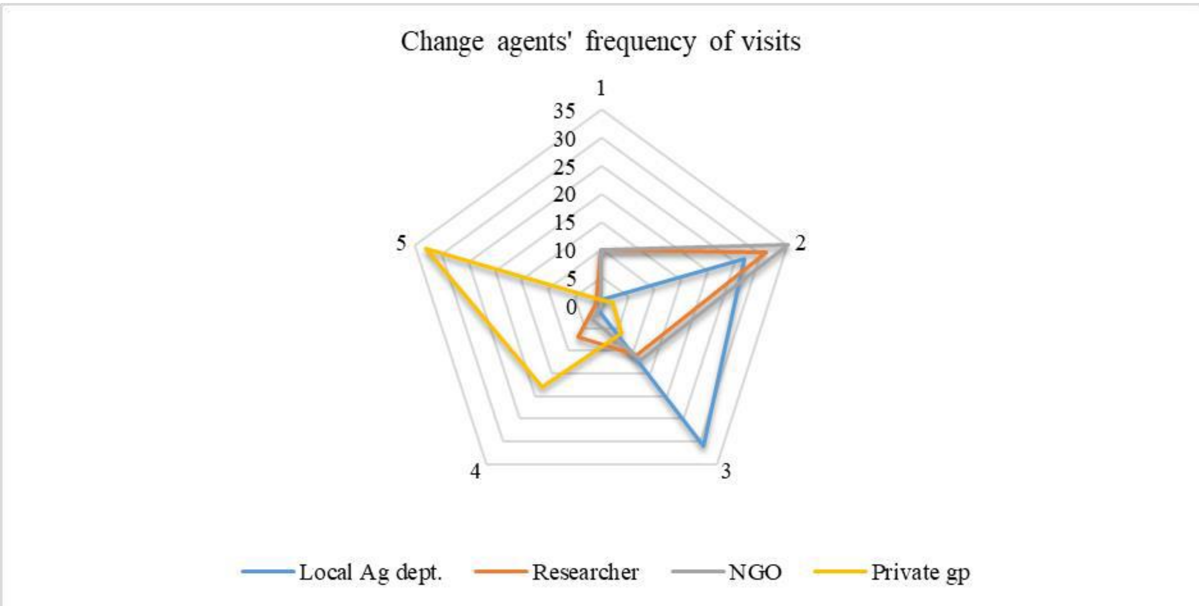

Fig. 4 Radar graph depicting the frequency of visits of change agents

ICTs serve as vital for conveying comprehensive knowledge about advances. Its contribution to bringing DSR technology to isolated regions, particularly in India, cannot be overlooked. It is statistically significant that the majority of individuals have access to TV, radio, and mobile. Use of a TV and a phone provides an additional benefit for learning more about how to advance DSR technology. When fertilizer recommendations were sent to farmers via RCM in the DSR practice, mobile devices were crucial.

3.6 Farmer's awareness-based determinants affecting adoption and diffusion

Awareness based determinants like knowledge about soil health, methods to maintain soil fertility and diversification options, factors responsible for yield gap, environmental changes and impact of climate change on crops were also assessed for all the farmers. Five-point Likerts were employed to evaluate the degree of favor/ preference. The figures of all the likerts are given in supplementary material (S1).

The analysis done to evaluate farmer's preference to maintain **soil fertility** revealed that residue incorporation was the most preferred choice, followed by crop rotation, while reduced tillage was the least preferred choice. Fertilization was moderately preferred and intercropping was less preferred. In this way, the study also investigated DSR based management practices. However, Odisha has a long history of rice-rice or rice-fallow cropping system, so diversification seems challenging.

While assessing the factors which affect the **yield,** in DSR, the highest number of respondents said that natural calamities affected the most, while lack of finances affected the least. Yield is moderately affected by pest and diseases while lack of knowledge and unavailability of proper equipment somewhat affect the yields. Precision land levelling and expertise of seed treatment are related to yield in DSR. Therefore, it can be concluded that DSR practice is knowledge intensive, and with proper equipment and pest and disease control, yield penalty can be tackled. In TPR, the yield was most affected by natural calamities, followed by pest and disease. Untimely/delay in sowing and harvesting also affected the yields in TPR. Labor shortages during the peak season of transplanting and delay in harvesting affect yield in TPR. Whereas, DSR rules out the issue of labor shortage.

With respect to climate change, majority of respondents (98%) indicated that yes, they had observed changes in the climate and environment over the last several years. When asked to list the effects, they said that increasing soil salinity, low rainfall, high temperatures, and the frequency of natural disasters like cyclones and drought were the most important ones. When respondents acknowledged that climate change was occurring, questions on how it affected agriculture were posed. 87% of farmers (n=120) highlighted that they have observed soil deterioration, while 62 % mentioned increased pest infestation and 52% cited that yield loss is the major consequence of the changing climate on agricultural production.

While investigating the **implications of COVID-19**, for DSR practitioners, marketing or selling their produce in market was the critical factor that impacted them the most, because due to COVID restrictions, the markets were not open and they could not sell the produce. On second rank was the availability of agri-inputs (the machinery and skilled labor for DSR) due to which the price of agri-inputs was high. For TPR practitioners, the demand and supply of labor for land preparation and transplanting was the most impacting factor. The second was marketing and then the availability of agri-inputs. The banking services for DSR and TPR were the least impacted because banks were mostly open during COVID-19. Due to scarcity of labor for TPR, DSR method of rice cultivation received a boost during the COVID pandemic.

3.7 Role of women in decision making

A disaggregated analysis of the present questionnaire and responses of 33% of the women farmers showed that in terms of their own income, information availability, and their capacity to acquire new technologies, women share control of family decision-making with men. These judgements for home agricultural production and technology selection are of utmost importance (Fig.5). This calls attention to the gender disparities between men and women in terms of women's accessibility to knowledge, availability of information, and capacity about developing technologies and emphasises closing these inequalities. There is testimony that women who are knowledgeable, informed, and competent handle household decisions more effectively. It was also noted that women's influence over decisions impacting household expenditures and personal income grew as land ownership increased.

Contribution of women in decision making				
			SDEV	
Role of women	DSR	TPR	DSR	TPR
Less than 25%	36	25	0.49	0.50
25-50%	10	19	0.38	0.47
More than 50%	14	16	0.43	0.45

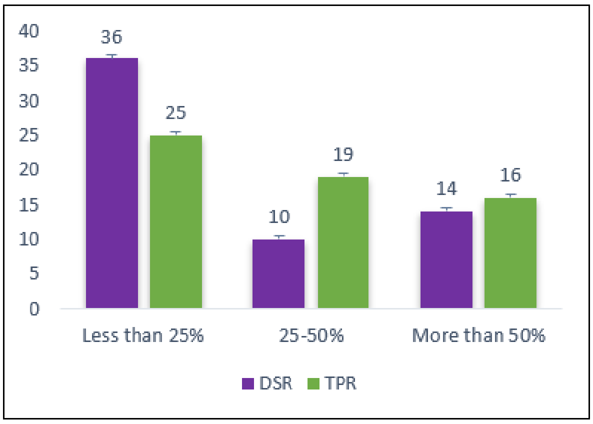

Fig. 5 Contribution of women in decision-making along with standard deviation

Nonetheless, while DSR requires less physical labour, some trade-offs can be seen. The hired labour is then impacted by this. Both the amount of hired labour performed by women and their corresponding remuneration have significantly decreased. The proportion of men and women hired as laborers are inversely correlated with the supply of equipment and service providers in the community. While it is crucial to use DSR to lessen the laborious tasks that women perform during transplant procedures, we also need to consider the trade-offs in terms of lost work and the resulting income for both men and women who rely on wage labour. It is necessary to discover alternative ways to make up for such losses. One such potential solution is to employ and assist women as mechanised service providers. Engaging women as mechanised service providers and supporting them in carrying out these entrepreneurial operations is one such viable approach. (Devkota et al. 2020).

4. Conclusions and recommendations

- The present study has quite emphatically demonstrated the determinants of adoption of DSR. In the current scenario, when the world community is facing water and labor scarcity and inclining towards resource conservation technologies, it is high time for wider adoption of DSR but there are certain limitations.
  - We still haven't identified ample arable rice varieties.
  - Crop establishment is a major issue.
  - Weed management is a challenge.
  - DSR being a knowledge intensive practice, capacity building of the farmers is lacking.

- A thorough modification of the farmers' traditional disposition and beliefs is necessary for an effective paradigm shift from the conventional rice establishing method to the DSR practice. Hand holding of the farmers through training and capacity building needs to done. It requires right kind of policy support and incentives, better skills, easy access to machinery, more involvement of women in decision making, frequent visits and detailed advice on each DSR component from change agents for faster upscaling of DSR in India and to initiate another green revolution.
- DSR has immense potential to provide greater economic returns and comparable levels of productivity to farmers when compared to TPR. It also has the potential to lessen GHG emissions and the unsustainable exploitation of ground water, which would positively assist the environment provided proper management practices are followed.

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Availability of data and materials (data transparency): The datasets generated during and/or analysed during the current study will be provided by the corresponding author on reasonable request.

Code availability (software application or custom code): Not applicable.

Ethics approval: Not applicable.

Consent to participate: Verbal and an informed consent was obtained from all the participating farmers prior conducting the interview.

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REFERENCES

1. Akter S, Rutsaert P, Luis J, Htwe NM, San SS, Raharjo B, Pustika A. 2017. Women's empowerment and gender equity in agriculture: A different perspective from Southeast Asia. *Food Pol* 69:270-279. https://doi.org/10.1016/j.foodpol.2017.05.003.
2. Alam MJ, Humphreys E, Sarkar MAR, Sudhir-Yadav. 2018. Comparison of dry seeded and puddled transplanted rainy season rice on the High Ganges River Floodplain of Bangladesh. *Eur J Agron* 96:120-130. https://doi.org/10.1016/j.eja.2018.03.006.
3. Bandumula N, Mahajan G, Kumar RM. 2018. Farm level and aggregate economic impact of direct seeded rice in Punjab. *J Exp Biol Agric Sc* 6:253-257.
4. Chaudhary A, Venkatramanan V, Mishra AK, Sharma S. 2022. Agronomic and Environmental Determinants of Direct Seeded Rice in South Asia. *Circ Econ Sust* 1-38. https://doi.org/10.1007/s43615-022-00173-x.
5. CSISA (2017) Cereal systems initiatives for South Asia (CSISA) annual report, cereal systems initiatives for South Asia (CSISA). http://csisa.org/wp-content/uploads/sites/2/2014/06/CSISA-Phase-III-Annual-Report-2016.pdf.
6. Das SR. 2012. Rice in Odisha. IRRI Technical Bulletin No. 16. International Rice Research Institute (IRRI), Los Baños, Philippines.
7. Dar MH, Chakravorty R, Waza SA, Sharma M, Zaidi NW, Singh AN, Singh US, Ismail AM. 2017. Transforming rice cultivation in flood prone coastal Odisha to ensure food and economic security. *Food Sec* 9:711–722. https://doi.org/10.1007/s12571-017-0696-9.
8. Devkota KP, Khanda CM, Beebout SJ, Mohapatra BK, Singleton GR, Puskur R. 2020. Assessing alternative crop establishment methods with a sustainability lens in rice production systems of Eastern India. *J Cleaner Prod* 244:118835. https://doi.org/10.1016/j.jclepro.2019.118835.
9. Ditzler L, Breland TA, Francis C, Chakraborty M, Singh DK, Srivastava A, Eyhorn F, Groot JCJ, Six J, Decock C. 2018. Identifying viable nutrient management interventions at the farm level: the case of smallholder organic Basmati rice production in Uttarakhand, India. *Agric Syst* 161:61-71. https://doi.org/10.1016/j.agsy.2017.12.010.
10. Gathala MK, Kumar V, Sharma PC, Saharawat YS, Jat HS, Singh M, Kumar A, Jat ML, Humphreys E, Sharma DK, Sharma S, Ladha JK. 2014. Reprint of "Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the Northwestern Indo-Gangetic Plains of India. *Agric Ecosyst Environ* 177: 33-46. https://doi.org/10.1016/j.agee.2013.06.002.

11. GRiSP (Global Rice Science Partnership). 2013. *Rice Almanac, 4th edition*. International Rice Research Institute, Los Banos, Philippines. http://irri.org/resources/publications/books/rice-almanac-4th-edition.
12. Humphreys E, Kukal SS, Christen EW, Hira GS, Balwinder-Singh, Sudhir-Yadav, Sharma RK. 2010. Halting the groundwater decline in North-West India- which crop technologies will be winners? *Adv Agron* 109:155-217.
13. Jha A, Singh KM, Meena M, Singh R. 2012. *Constraints of Rainfed Rice Production in Eastern India: an Overview.* Available at SSRN 2061953. https://ssrn.com/abstract=2061953.
14. Kumar R, Batra SC. 2017. A comparative analysis of DSR technology Vs. transplanted method in Haryana. *Economic affairs* 62(1):169.
15. Kumar V, Ladha JK. 2011. Chapter six - direct seeding of rice: recent developments and future research needs. In: Donald LS (ed) *Advances in Agronomy*. Academic Press, pp 297-413. https://doi.org/10.1016/B978-0-12-387689-8.00001-1.
16. Laik R, Sharma S, Idris M, Singh AK, Singh SS, Bhatt BP, Saharawat Y, Humphreys E, Ladha JK. 2014. Integration of conservation agriculture with best management practices for improving system performance of the rice-wheat rotation in the Eastern Indo-Gangetic Plains of India. *Agric Ecosyst Environ* 195:68-82. https://doi.org/10.1016/j.agee.2014.06.001.
17. Latif MT, Falak S, Adnan B, Muhammad A, Naeem F, Muzzammil H. 2017. A field survey to identify the problems in adaptability of direct seeded rice. *Azarian J Agri* 4(4):139-144.
18. Lobell DB, Cassman KG, Field CB. 2009. Crop yield gaps: their importance, magnitudes, and causes. *Annu Rev Environ Resour* 34:179.
19. Mishra AK, Khanal AR, Pede VO. 2017. Is direct seeded rice a boon for economic performance? Empirical evidence from India. *Food Pol* 73:10-18. https://doi.org/10.1016/j.foodpol.2017.08.021.
20. Mishra AK, Shinjo H, Jat HS, Jat ML, Jat RK, Funakawa S, Sutaliya JM. 2022. Farmers' perspectives as determinants for adoption of conservation agriculture practices in Indo-Gangetic Plains of India. *Resources, Conservation & Recycling Advances* 15:200105. https://doi.org/10.1016/j.rcradv.2022.200105.
21. Mohanty S, Yamano T. 2017. Rice food security in India: emerging challenges and opportunities. In: Mohanty S, Chengappa PG, Hedge M, Ladha JK, Baruah S, Kannan E, Manjunatha AV (eds.) *The Future Rice Strategy for India*. Academic Press, Oxford OX5 1GB, United Kingdom, pp 1-13. https://doi.org/10.1016/B978-0-12-805374-4.00001-4.
22. Ngwira A, Johnsen FH, Aune JB, Mekuria M, Thierfelder C. 2014. Adoption and extent of conservation agriculture practices among smallholder farmers in Malawi. *J Soil and Water Cons* 69 (2):107–119.
23. Nwele JO. 2016. Economics of rice production and marketing in Nigeria: A study of Ebonyi state. *Inter J Res in Business, Management and Accounting* 2(5):17-37.
24. Quilty JR, McKinley J, Pede VO, Buresh RJ, Correa Jr TQ, Sandro JM. 2014. Energy efficiency of rice production in farmers' fields and intensively cropped research fields in the Philippines. *Field Crop Res* 168:8-18. https://doi.org/10.1016/j.fcr.2014.08.001.

25. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. 2007. Weed management in direct-seeded rice. *Adv Agron* 93:153-255. https://doi.org/10.1016/S0065-2113(06)93004-1.
26. Rogers EM. 2003. *Diffusion of innovations*, 5th edn. New York: Free Press.
27. Sapkota S, Sapkota S. 2019. Benefit cost analysis of different rice varieties in Kapilvastu district, Nepal. *Int J Appl Sci Biotech* 7(2):222-226.
28. Singh VP, Singh RK (eds). 2000. *Rainfed Rice: A Sourcebook of Best Practices and Strategies in Eastern India.* International Rice Research Institute, Los Banos, Philippines. http://books.irri.org/8186789022_content.pdf.
29. Soriano JB, Wani SP, Rao AN, Gajanan SL, Gowda JA. 2018. Comparative evaluation of direct dry-seeded and transplanted rice in the dry zone of Karnataka, India. *Philippine J Sci* 147 (1):167-176.
30. Sudhir-Yadav, Humphreys E, Kukal SS, Gill G, Rangarajan R. 2011. Effect of water management on dry seeded and puddled transplanted rice: Part 2: water balance and water productivity. *Field Crop Res* 120:123-132. https://doi.org/10.1016/j.fcr.2010.09.003.
31. Sudhir-Yadav, Kumar V, Singh S, Kumar RM, Sharma S, Tripathi R, Nayak AK, Ladha JK. 2017. In: Mohanty S, Chengappa PG, Mruthyunjaya, Ladha JK, Baruah S, Kannan E, Manjunatha A.V.B.T.-T.F.R.S. (eds) *Growing Rice in Eastern India: New Paradigms of Risk Reduction and Improving Productivity*. Academic Press, pp 221-258. https://doi.org/10.1016/B978-0-12-805374-4.00008-7.
32. USDA. 2021. India – Area, Yield and Production. IPAD (International Production Assessment Division). Foreign Agricultural Division, US Department of Agriculture. https://ipad.fas.usda.gov/
33. Wang W, Peng S, Liu H, Tao Y, Huang J, Cui K, Nie L. 2017. The possibility of replacing puddled transplanted flooded rice with dry seeded rice in central China: a review. *Field Crop Res* 214:310-320. https://doi.org/10.1016/j.fcr.2017.09.028.
34. Yaduraju NT, Rao AN, Bhullar MS, Gill JS, Malik RK. 2021. Direct-Seeded Rice (DSR) in India: New opportunities for Rice Production and Weed management in post-COVID-19 pandemic period. *Weeds – J Asian-Pacific Weed Sci Soc* 3 (2): 30-48.
35. Younas M, Rehman MA, Hussain A, Ali L, Waqar MQ. 2015. Economic comparison of direct seeded and transplanted rice: Evidences from adaptive research area of Punjab Pakistan. *Asian J Agri Biol* 4(1):1-7.

Web references

https://www.census2011.co.in/census/district/410-khordha.html