Adaptation to climate change and variability: a case of direct seeded rice in Andhra Pradesh, India

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ABSTRACT

Farmers, researchers and policy-makers are increasingly concerned about the potential impacts of climate change. Researchers are using various climate models to assess the impacts and identifying relevant alternative adaptation strategies to mitigate climate change. In India, rice is the major cereal crop grown and is influenced due to climate change and variability, inadequate water supply, labour shortage and methane emissions from rice ecosystems. This necessitates adoption action and upscaling of key adaption strategies like direct seeded rice (DSR) using validated data from rice growing areas in India. The study used experimental data of 2010–2014 and field survey data of DSR and non-DSR farmers collected during 2014. Results show that DSR method has incurred less tillage and labour costs by eluding puddling and transplantation by labour. Large-scale adoption of DSR was observed during 2012–2015 in Guntur district of Andhra Pradesh. This was mainly due to the delayed monsoon and water supply, reduction in cost of cultivation, capacity building of stakeholders and their active involvement in awareness and training programmes. The study has demonstrated that integrated extension approach in technology dissemination and scaling-out through stakeholder integration is crucial. However, a mission mode framework is needed for technology upscaling at system level.

Key words | direct seed rice, Krishna River basin, stakeholder integration, upscaling framework, water management, water use efficiency

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INTRODUCTION

Food production in India is largely dependent on irrigated agriculture. Increase in population and urbanisation, in addition to climate change and variability, will have a significant impact on the availability of water resources. In arid and semi-arid regions of India, any shortfall in water supply due to climate change will enhance competition for water use to a wide range of economic, social and environmental applications. The population growth with the improved living conditions also increases the demand for food production and thereby increases the demand for water multiple-fold in the river basins (UNESCO-WWAP 2009). The major proportion of water available in Indian river basins is used for irrigation of rice and thus major challenges to water management are posed, especially during unfavourable weather or climatic conditions. Around 95% of the cultivated area under rice is irrigated, and requires water of about 12,000 m^3 to 25,000 m^3 per ha for one season depending on the soil texture, structure and profile conditions (Reddy & Reddi 1995). Of all the major cereal crops grown in India, rice constitutes 24% of the total food grains produced, contributing almost 96 million tonnes. The popular method of rice cultivation so far has

doi: 10.2166/wcc.2018.141

been transplanting in ponded water that ensures steady yields (Chen *et al.* 2009). This may not be the case in the future with growing climate uncertainty, insufficient irrigation water in the canal commands, increased labour requirement and increased emissions. The temperature rise will also negatively impact rice yields as they are being grown to their threshold (Kelkar & Bhadwal 2007). The projected climate scenarios for mid (2021–2050) and end centuries (2071–2100) in the Krishna River Basin of India also show a change in the future water availability, which impacts rice production (Palanisami *et al.* 2011).

Labour requirement is also comparatively higher in transplanted rice cultivation. About 25 to 37 labourers (man-days) per hectare are required for rice transplanting, 50 for weeding/hectare and about 25 man-days/per hectare for harvesting (Prakash *et al.* 2013; Kakumanu *et al.* 2017). The availability of labour is becoming problematic in most Indian states, as rural people are migrating to nearby cities and towns for higher wages or being hired in the government social welfare programmes (e.g., the National Rural Employment Guarantee programme). Hence, the cost of hiring labour has significantly increased during recent years (Farooq *et al.* 2011). For example, in the lower Krishna River basin (Krishna, Guntur and Prakasam districts) of Andhra Pradesh state, costs for labour in rice cultivation accounted for 29% of the total cultivation costs during 2006–2007, and it increased to 49% in 2010–2011 (Kakumanu *et al.* 2017).

It is also a known fact that rice fields emit methane into the environment that contributes to global warming (Pathak *et al.* 2013). Emissions from flooded fields are higher than those from drained fields (Komiya *et al.* 2010). Methane is generated when organic matter decays in anaerobic conditions. Hou *et al.* (2000) reported that the factors affecting methane and nitrous oxide emissions are soil temperature and soil redox potential, net irradiance and organic matter content. The IPCC Fourth Assessment Report states that agriculture accounts for 50% of methane emissions, and 10–20% of these emissions come from rice production alone (Reiner & Aulakh 2000). Overall, South and East Asia are responsible for 82% of methane emissions from rice production. Annually, 4.5 million tonnes of methane are emitted from rice cultivation in India (Pepsico International 2009). Methane emissions from Indian rice fields are significant and therefore there is a need to shift to more climate resilient rice cropping systems that can also help in methane reduction (Lakshmanan *et al.* 2009).

Hence, to sustain rice production and ensure food security with these challenges, new adaptation strategies have to be developed and up-scaled. The delayed onset of monsoon, insufficient irrigation water at the tail ends of canal commands, increased labour requirement and costs are forcing farmers to adapt to different management practices like direct seeded rice (DSR) and alternate wetting and drying (AWD) for rice (Chapagain *et al.* 2011; Joshi *et al.* 2013; Mahajan *et al.* 2013; Li *et al.* 2014). However, the practices have not been adopted in large scale due to the lack of timely and sufficient scientific information and dissemination framework. Much of the scientific or technical information developed on DSR is at research station level (Yadav *et al.* 2007, 2011; Ali *et al.* 2014; Li *et al.* 2014) with modelling aspects (Liang *et al.* 2015; Palanisami *et al.* 2015). Hence, the present study analysed the performance of DSR in actual field conditions and documented the results along with the development of an upscaling strategy with policy prescriptions.

CASE AND RESEARCH METHODS

DSR can be practised through three methods, namely, (1) dry seeding, (2) wet seeding and (3) water seeding by avoiding the nursery and transplantation (Joshi *et al.* 2013). In the case of dry seeding, seeds are sown directly into dry soil at a depth of 2–3 cm, immediately after the pre-monsoon showers. The method is suitable for a rain-fed and irrigated environment with precise water control. In irrigated areas, the dry seeded fields can be converted into wet method based on the availability of water from canals. Irrigation can be provided 45–60 days after sowing and then managed as a wet system. In wet seeding, pre-germinated seeds are broadcast or sown in the puddled soils. It is most favourable to rain-fed lowlands and irrigated areas with good drainage facilities. The wet method is practised in Malaysia, Thailand, Vietnam, Philippines and Sri Lanka (Pandey & Velasco 2005). Drum seeded rice is recommended in India using the wet method, where seeds are sown in line on the puddled soil. In the water seeding method, seeds are broadcast in standing water (5–10 cm) in areas where red rice or weedy rice problem exists.

In the present study, the first dry seeded method was followed, which requires less water, labour and has lower cultivation costs with comparatively equal or slightly higher grain yields than traditional transplanting paddy rice method (Yadav *et al.* 2011; Li *et al.* 2014; Liang *et al.* 2015). The crop matures earlier than the transplanted paddy rice (Bhushan *et al.* 2007), but the weed growth is higher in DSR and requires the use of selective pre- and post-emergence herbicides to address the problem (Chauhan & Opeña 2012). Timely sowing of rice through the dry seeded method provides the possibility to take up a second crop (blackgram, greengram, etc.) on time during the year.

Field observations and data collection

The study was conducted under Nagarjuna Sagar Project (NSP) area of the Krishna River basin falling in Guntur district of Andhra Pradesh (Figure 1). The NSP distributes water through right and left bank canals covering 0.47 and 0.42 million hectares, respectively. The right canal supplies water to Guntur and Prakasam districts, and the left canal to Nalgonda, Khamman and Krishna districts.

Guntur district (15°44′N, 80°55′E) was identified for the study covering the NSP right canal and Delta area in the district. The long-term mean annual rainfall in Guntur is 815 mm, where 70% falls between June and September from the southwest monsoon, and the remaining 30% from the northeast monsoon (October to December). Long-term mean annual air temperature is high in April and May (36 to 43 °C), and milder in August to October (17 to 35 °C). Weather data for the study areas were acquired from nearby meteorological stations located at the Regional Agricultural Research Station, Lam, in Guntur. The soils of the Guntur area are dominated by deep black cotton soils with a silty clay loam texture, and contain, on average, low organic carbon (0.55%), and pH range 8.1–9.3.

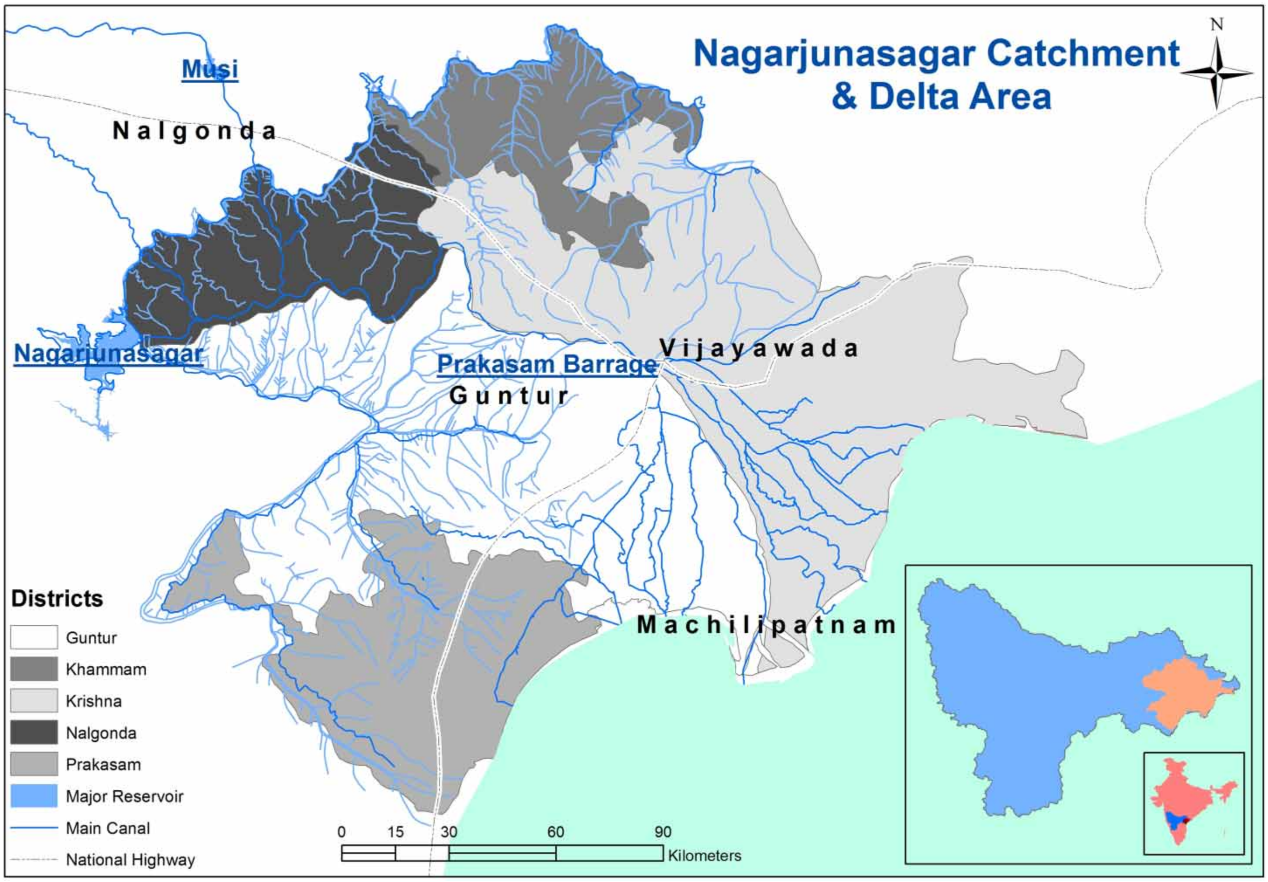

Figure 1 | Nagarjuna Sagar Project and Krishna Delta command area districts under Krishna River basin in India.

The DSR method was validated on farmers' fields ($n=50$) compared with the traditional transplantation method from Kharif 2010 to 2014 (the Indian cropping system is classified into Kharif and Rabi seasons. The Kharif season starts with the onset of monsoon and falls during the month of June/July to October/November, whereas Rabi season falls between November and March), in order to generate relevant biophysical observations and economic data. The two methods were sown simultaneously in the same farmers' fields for comparison on a pilot basis. The key biophysical observations and cost of cultivation for both methods were collected from 2010 to 2014 and summarized in the following section (refer to Table 1). The villages covered for validating/piloting of DSR through

Table 1 | DSR field observations from 2010 to 2014

	2010 Kharif		2011 Kharif		2012 Kharif		2013 Kharif		2014 Kharif	
Particulars	**DSR**	**Traditional**	**DSR**	**Traditional**	**DSR**	**Traditional**	**DSR**	**Traditional**	**DSR**	**Traditional**
Nursery preparation (INR/ha)	0	1,150	0	1,423	0	1,764	0	2,282	0	3,023
Main land preparation (INR/ha)	2,200	5,687	2,400	5,787	3,825	5,234	4,762	5,431	4,357	9,555
Seed and sowing (INR/ha)	1,540	6,440	1,540	6,720	2,348	8,565	2,852	8,903	2,315	7,976
Manures and fertilizers (INR/ha)	8,000	7,221	9,000	8,240	13,274	16,184	14,794	17,856	13,198	13,483
Plant protection (INR/ha)	6,011	6,123	6,214	6,324	6,678	9,425	7,254	9,548	13,559	13,183
Cost of irrigation (INR/ha)	1,000	899	1,200	1,000	1,780	1,155	1,984	2,108	1,700	1,700
Weeding (INR/ha)	4,200	3,576	4,100	3,765	2,825	4210	7,068	7,750	4,098	3,262
Harvesting, threshing, winnowing and transportation (INR/ha)	14,721	14,647	15,732	15,652	19,179	17,012	21,824	21,786	15,950	15,885
Interest on variable cost (IVC) (INR/ha)	589	715	628	764	780	993	946	1,182	862	1,064
Total variable cost (INR/ha)	38,261	46,458	40,814	49,675	50,689	64,542	6,1484	76,846	56,040	69,130
Land tax (INR/ha)	625	625	750	750	750	750	750	750	750	750
Land lease amount (INR/ha)	16,456	16,456	17,000	17,000	19,320	20,526	27,900	27,082	29,716	29,631
Interest on fixed cost (INR/ha)	285	285	296	296	335	355	478	464	508	506
Total fixed cost (INR/ha)	17,366	17,366	18,046	18,046	20,405	21,631	29,128	28,295	30,973	30,887
Total cost (INR/ha)	55,626	63,823	58,860	67,721	71,093	86,173	90,611	10,5142	75,540	88,895
Yield (qt/ha) (INR/ha)	48	46	67	66	60	54	68	66	68	67
Price realization (INR/qt)	1,132	1,132	1,152	1,152	1,857	1,857	1,710	1,710	1,720	1,720
Straw yield (qt/ha)	198	204	208	215	212	217	210	213	212	222
Straw price (INR/ha)	6,000	6,000	7,000	7,000	10,000	10,000	11,000	11,000	10,000	10,000
Gross returns (INR/ha)	59,804	57,676	84,622	82,606	121,420	110,278	127,280	123,860	127,354	125,491
Net returns (INR/ha)	4,178	−6,148	25,762	14,885	50,327	24,105	36,669	18,718	51,814	36,596
Production cost (INR/100 kg)	1,170	1,398	874	1,032	1,185	1,596	1,333	1,593	1,107	1,324
BC ratio (INR/ha)	1.08	0.90	1.44	1.22	1.71	1.28	1.40	1.18	1.69	1.41
Water utilized (m^3/ha)[a]	9,950	12,910	8,680	11,270	11,090	13,320	14,680	16,520	10,790	13,530
WUE (kg/m^3)[b]	0.48	0.35	0.78	0.58	0.54	0.41	0.46	0.40	0.63	0.50

[a]Water data from field observations, $n=50$.
[b]Water use efficiency (WUE) is defined as the amount of produce obtained per unit of water used, 1 USD = 64 INR.

action research are Jonnalagadda village (Guntur rural mandal), Dondapadu village (Narsaraopet madal) and Muppalla village and mandal of Guntur district. The data generated from the pilots were used for the dissemination of DSR practice benefits and up-scaled in other villages/ regions of the district.

For analysis, data from 100 farmers were collected, of which 50 were adopting DSR and 50 practising the traditional transplantation method from the non-piloting sites/villages in the district under Krishna Western Delta during 2014. Data were collected from nine villages (Alapadu, Appikatla, Ganapavaram, Jammulamadugu, Lakshmipuram, Modukur, Mulpuru, Narsayapalem and Nidubrolu) randomly based on the village-wise adoption information collected from the Department of Agriculture, Guntur district in 2014. As the upscaling process of DSR adoption in the district was initiated in a successful way, data related to the input, output and perceptions of farmers in adopting DSR were collected. Water application was measured by using Replogle, Bos, Clemmens (RBC) flumes in the validation/piloting sites. An RBC flume of 50 litres per second capacity was designed to use in small field channels for more accurate flow measurements. A calibration chart was developed to correlate the depth of water flow above the crust (placed at the bottom of the flume with a height of 10 cm for free flow conditions) with flow of water in litres per second. Data on the number of irrigations and depth of irrigation applied were collected from surveyed farmers to estimate the water application.

Analytical tools

Comparison of various input levels in the traditional transplantation method with DSR was done in the study. This provided cross-sectional data for the two methods in rice. To test the significant difference of input and output mean, paired t-test was used.

Difference of means for the two methods was tested for various inputs including seed (kg/ha), labour (man-days), fertilizer used (kg/ha), pesticide applied (kg/ha), total water used (m^3) and yield (kg/ha). Effective rainfall from the block was also measured and added to the irrigation to make the total water application.

A multiple linear regression model was fitted to study the functional relationship between the inputs and outputs, which is mathematically expressed as:

$$Y_i = \beta_0 + \sum_{j=1}^{k} \beta_j X_{ji} + u_i \tag{1}$$

where Y_i is the dependent variable, X_j is the jth number of independent variables, β_0 is the intercept term, β_j is the partial regression coefficient of X_j, u_i is the error term. In the Cobb–Douglas production function (Gujarati 2004), it is expressed as:

$$Y_i = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots\ldots X_n^{\beta_n} e^u \tag{2}$$

The parameters of the Cobb–Douglas production function are β_0, β_1, $\beta_2, \ldots \beta_n$. β_0 is the efficiency parameter, since for every positive input combination, the greater β_0, the greater is the level of output. β_1, $\beta_2, \ldots \beta_n$ are the input intensity parameters of X_1, $X_2, \ldots$ and X_n, respectively. They represent the elasticities of output with respect to individual inputs.

The production function given in the above equation can be influenced by development in the technology or variation in weather. Hence, technology or adaptation specific dummy variable D_t was included in the function, such that:

$$\ln Y_i = \ln \beta_0 + \beta_1 \ln X_{1i} + \beta_2 \ln X_{2i} + \ldots\ldots. \beta_n \ln X_{ni} + \sum_{t=2}^{T} \delta_t D_{it} + u_i \tag{3}$$

where $I = 1, \ldots$, n sample; t refers to the adaptation practice (DSR and traditional method); $D_{it} = 1$ if $t =$ DSR and 0 otherwise (traditional method); X_1 to X_n refers to the inputs (seed, fertilizer, pesticides, labour and irrigation) Equation (3) was used in the analysis to estimate the impact of adaptation practice.

Farmers' perceptions on direct seeding method as an adaptation measure were collected. Garrett ranking was applied to analyse the perception data (Garrett & Woodworth 1971). Farmers were asked to assign ranks for adapting DSR and the constraints faced. Ranking is an expression of the respondent's priority about their thoughts and feelings. The orders of the merit assigned by the respondent were converted into ranks using the formula. As a first step, the per cent position of each rank was found by the following formula:

$$\text{Percent position} = [100(R_{ij} - 0.5)]/N_{\text{j}}$$

where R_{ij} = rank given for *i*th items by the *j*th individual and N_j = number of items ranked by *j*th individual.

The per cent position of each rank was obtained by converting into scores by referring to the table given by Garrett & Woodworth (1971). The respondents were requested to rank the opinions/reasons relevant to them according to the degree of importance. The ranks given by each of the respondents were converted into scores. Then, for each reason, the scores of individual respondents were added together and divided by the total number of respondents. These mean scores for all the reasons were arranged in descending order and ranks were given. By this method, the accuracy in determining the preference was obtained.

IMPACT OF DSR

In India, the majority of rice-growing farmers follow the traditional rice transplantation method with the onset of monsoon and then depend on the release of canal water for irrigation. With the delayed onset of monsoons and droughts, farmers face problems of water shortage leading to failure of crops sown, or in some cases, they delay sowing or transplanting. The tail-end farmers in the canal commands (especially in Krishna River basin) are increasingly adopting DSR due to better dissemination of available information, water scarcity and less labour availability. The validated field observations of DSR illustrate that the seed and sowing cost reduced by 68–77% when compared to the traditional transplantation method (Table 1). The variable cost was also significantly less with a range from INR 8,000 to 15,000 per hectare. This was mainly due to reduction in land preparation, which raises nursery and transplantation costs. Only two labour man-days were used, on average, in DSR, as compared to 25 man-days in the transplantation method. The water use recorded by RBC flumes from 2010 to 2014 showed that there is an overall reduction of 2,500 m^3 (11–23%) in water application. The yield difference between DSR and the transplantation method also ranged from 1 to 6 qt/ha. The WUE, gross margins and cost–benefit ratio over the years also depicted the benefits of DSR (Table 1). The irrigation cost includes both water charges (Rs/ha) and operational cost for irrigation (labour). The operational cost has varied between the two methods and increased the cost in DSR due to the transport of water from nearby sources (ponds/lakes). This is due to the delayed release of canal water from the irrigation project and break in the rainfall trend. The scheduling of irrigation after 45 days of sowing has reduced the water use by 11–23%.

The data collected from surveyed farmers ($n = 100$) on DSR and traditional transplantation methods were analysed for comparison. The mean age of the sample collected for the study was 50 years with a range of 38 to 70 years. The education level ranged from primary to post-graduation with an average of nine years' schooling. Farmers' experience was relevant and had implications for adopting new technologies. In the current study, the average sample experience in farming was about 26 years.

Farmers in the sample had varied farm size ranging from marginal to large (0.2 to 32 hectares) with black clay soils. The results from the paired t-value (Table 2) illustrate that there is a significant reduction in the means of seed rate, labour and irrigation, reducing the cost of input application for the farmers in DSR. The labour requirement was reduced by 20%, and was found to be 45% in the case of Punjab (Pathak *et al.* 2013).

Fertilizer and pesticide application did not vary at a significant level with DSR adoption. However, increase in yields was noticed with the reduced number of irrigations during the tillering/vegetative phase. The total water application reduced from 2,000 to 2,500 m^3 (Tables 1 and 2) in DSR due to the early sowings without puddling.

Production function fitted estimated the changes in rice production due to the adoption of DSR. Table 3 presents the production elasticities of rice. The yields of rice for DSR and traditional transplantation method were regressed against the predominant factors of production. The R^2 value of 63% indicates that the rice yield variation among the total of farmers was explained by the selected independent variables in the study area (Table 3). The production elasticities for labour, fertilizer and technology adaptation are positive but significant for labour and DSR adaptation.

Table 2 | Comparison of means for DSR and traditional transplanting method

Variables	Direct seeding	Traditional transplantation	Mean difference	Std. error mean	t-value
Seed rate (kg/ha)	40.3	51.5	−11.2	0.4	−23.1
Fertilizer applied (kg/ha)	487.2	482.3	4.9	5.5	0.8
Pesticide applied (kg/ha)	3.1	3.3	−0.1	0.1	−1.6
Labour used (man-days/ha)	54.7	68.0	−13.3	0.7	−16.9
Irrigation water applied (m^3)[a]	8,969	10,990	−2021	15.7	−12.8
Yield (qt/ha)	62.80	56.71	6.09	28.6	21.3

Source: Farmers' survey ($n = 100$).
[a]Number of irrigations and depth of irrigation applied per hectare.

Negative sign observed for seed, pesticide and irrigation water use indicated the need for reduction in the use of the respective resources. The irrigation water can be reduced further by integrating the AWD manner instead of continuous wetting during the vegetative phase.

Farmers' perceptions on DSR adoption in the study area were also analysed by Garrett ranking. Positive responses were given concerning the reduced costs by avoiding transplantation, increased tiller length, resistance to lodging, free tillering with a greater number of tillers, lower occurrence of pests and diseases due to less humidity, a deeper root system that absorbed nutrients effectively from deeper layers and lower water demand in the initial crop growth stages (Table 4). Response was also given on the increase of nutrient use efficiency assuming methane emissions are reduced due to the controlled irrigation and spacing in the DSR method. However, exact methane emissions were not measured due to the limitations of the study, but need to be addressed in future research studies.

Farmers also responded to the constraints in DSR adoption. It is understood that the soil leveling is important in DSR with controlled irrigation practice (Table 5). The weed problem is greater in the initial phase of the crop (Mahajan *et al.* 2013). Tillage serves only as a temporary means of weed control because the soil contains many

Table 3 | Impact of DSR adaptation on yield

Variables	*B*	Std. error	t-value	Sig.
Constant	8.554	0.232	36.834	0.000***
Seed in kg/ha	−0.055	0.034	−1.616	0.108
Total fertilizer used in kg/ha	0.020	0.022	0.882	0.379
Total pesticide used in kg/ha	−0.006	0.008	−0.688	0.492
Total labour days/ha	0.050	0.019	2.664	0.008***
Irrigation water (m^3)	−0.003	0.022	−0.128	0.899
Dummy for adaptation practice (D = 1 for DSR and 0 for traditional method)	0.097	0.010	9.527	0.000***
R^2	0.63			
Durbin–Watson[a]	1.997			

***Significant at 1% level.
[a]Durbin–Watson is a statistic test used to detect the autocorrelation and the value of 2 indicates no autocorrelation.

Table 4 | Farmers' perceptions on advantages of DSR adoption

Perceptions	Garrett score
Reduces the cost compared to transplanting rice	63.31
Panicle length is higher compared to transplanting rice	60.76
Crop is resistant to lodging in DSR	60.05
DSR is best method, provided there is acquaintance of perfect weed control	54.88
DSR integrated with alternate wetting and drying will facilitate aeration to the root system	53.05
Pests and diseases occurrence are minimized	50.00
Controlled irrigation in DSR reduces the methane emission and increases nutrient use efficiency	49.57
Root system will be deeper, thereby it absorbs nutrients from deeper layers	47.22
Free tillering is observed	42.72
Productive tillers are greater compared to transplanted rice in a sq. m area	41.61
Thinning operation enhances nutrient uptake	30.72

Table 5 | Constraints in adapting DSR

Perceptions	Garrett score
Perfect leveling should be a provision for DSR	66.10
Control of weed growth in the initial phase	59.35
Heavy rains in the initial 10 days may damage crop	56.60
Problem of dropping of panicles during manual labour harvesting	36.30
Drainage should be a provision after heavy rainfall	31.65

ungerminated weed seeds. Ploughing may bury weed seeds at a depth that prevents germination but may also expose other, once deeply buried seeds to conditions favourable for germination (Stoskopf 1985; Kumar & Ladha, 2011).

Heavy rains immediately after seed sowing will wash out the seed from the field, therefore care has to be taken by considering forecast information. Farmers also responded on the dropping of panicles during manual labour harvest due to the increased number of tillers and panicles. Draining of water in the initial phase of the crop during heavy rains is also a problem in the poor drainage areas.

UPSCALING APPROACH AND ITS IMPACT

Framework of upscaling

The constraints may seriously impact the agricultural technology development and extension. Hence, there is a need for an emphasis on institutional change and technology pathways that are more effective (Hall *et al.* 2003; Watts *et al.* 2003). In the last 20 years, there has been a change in the thinking on the nature of the agricultural technology development and promotion process (Rasheed & Hall 2002). In the development of a technology or modified practice adoption and dissemination, stakeholder participation in the process is very important. Active stakeholder participation from farmers to the policy level is needed for the success of any technology adoption. Within the existing institutional arrangements working towards specified goals of adoption is challenging. There is a need for more awareness and capacity building programmes targeted towards farmers, government agencies and policy-makers.

The stakeholder mobilization in the present study followed an integrated participatory framework (Figure 2). The key steps included were the identification of water management practices/interventions for validation followed by technology assessment and refinement in the farmers' fields. The interventions were developed as technology packages of practices. Data recording procedures were developed to establish a common database for comparison and analysis. Capacity building programmes were also developed for farmers and the Department of Agriculture (DoA), and the Irrigation & Command Area Development (I&CAD) officials in the region. Dissemination materials were produced in local languages and coupled with stakeholder workshops. The institutionalization of the interventions and innovations and resource mobilization and management were achieved.

In the process, farmers, scientists, agricultural department, irrigation department and media were brought together which helped in building trust. The pros and cons of the practice were discussed in the workshops, as listed in Tables 1 and 2. Television programmes such as *Annadatha* (television programme broadcast for farmers) and daily newspapers were used for disseminating information about DSR to a wider audience. The Agricultural Technology Management Agency (ATMA), which is part of the Department of Agriculture also published the validated results for dissemination purposes. Most of the stakeholders involved in the upscaling and disseminating of the practice were not involved through a formal channel. Framing all the activities into the

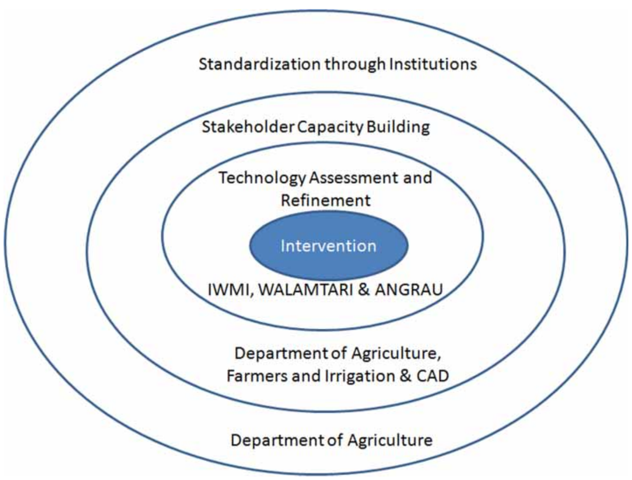

Figure 2 | Approach followed in upscaling of DSR.

extension cycle, we can see a step-wise pattern of invention, innovation and institutionalization.

The area under the DSR system in 2010 was limited only to 100 ha, but it increased to 103,210 ha by 2015 in Guntur district due to the efforts made to upscale with technical backstopping (Table 6). The adopted area has increased to 64% of the actual rice sown area in the district.

The Department of Agriculture has also taken serious measures to promote DSR by conducting a large number of campaigns, group discussions and result demonstrations at village level. The timely supply of seed drills (253 seed drills supplied during 2011–2014) on a subsidy basis by the Department of Agriculture has also increased adoption in the district.

Impact of adaptation

The impact of adaptation was seen three-fold, namely, additional benefits/revenue, savings on fuel consumption, and intensification of agricultural cropped area. The additional benefits generated by the adoption of DSR were estimated by considering the gross margin difference with the transplantation method and area adopted in the district. The benefits have varied over the years due to the climatic conditions and market price (Figure 3). Farmers/trainers experienced in DSR have been asked for help by other new farmers, paying contractual wages, which is generating additional income to them (case of Jonnalagadda village).

Land preparation and puddling of rice crops need machine/tractor power. The transplanting method requires about 72.25 litres of diesel/ha from land preparation to harvest of the crop. In the dry method of DSR, 47 L/ha is sufficient. DSR does not need puddling which helps in the saving of energy used. Considering the diesel savings of 25.16 L/ha, the total diesel savings were 2.5 million litres when extrapolated to the entire area under DSR (Figure 4). This is equivalent to the reduction of 6,788 metric tons of CO_2 emissions (2.62 kg of CO_2 per litre).

As shown in Table 7, the total methane emissions from traditional rice transplanted fields were estimated to be 315 kg CH_4 per hectare (Joshi *et al.* 2013). In contrast for DSR, the estimated methane emissions were 220 kg CH_4 per hectare during Kharif season. Referring to these values, adaptation of DSR in Guntur district has reduced about 9,785 tons of CH_4 emissions during 2015. DSR adaptation is not only saving costs, labour, and time but also reducing greenhouse gas, particularly methane that causes global warming. DSR is reducing the methane emissions by 30–38% in India (Joshi *et al.* 2013; Pathak *et al.* 2013). The reduced emissions of these gases helps in climate change adaptation and mitigation.

Table 6 | Increase of direct seeded rice share in Guntur district during 2010–2015

Year	Actual area (ha)	DSR area (ha)	% Share of DSR over actual area
2010	271,072	100	0.04
2011	281,790	400	0.14
2012	174,669	19,893	11.39
2013	280,060	42,050	15.01
2014	255,607	80,182	31.37
2015	160,608	103,210	64.27

Source: Department of Agriculture, Guntur, Andhra Pradesh.

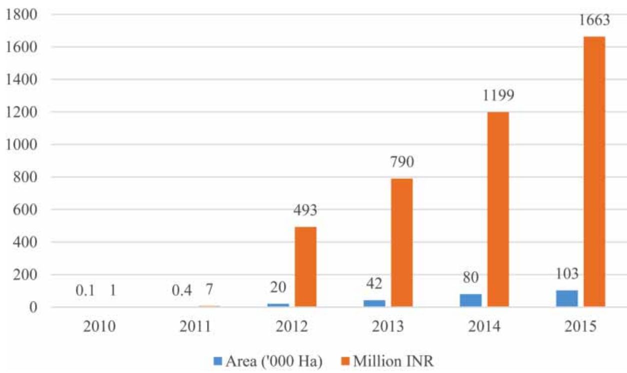

Figure 3 | Additional revenue with DSR adaptation (2010–2015).

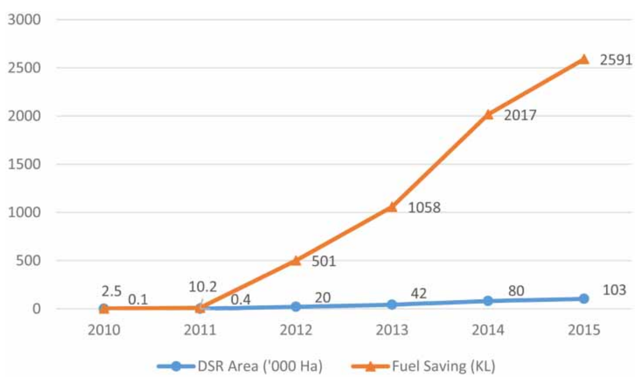

Figure 4 | Fuel saving with adoption of DSR during 2010–2015.

Table 7 | Estimated methane emissions (kg) for the area under DSR adoption

Particulars	2004 (kg CH_4/ha)[a]	2010	2011	2012	2013	2014	2015
Traditional	315	31,500	126,000	6,300,000	13,230,000	25,200,000	32,445,000
DSR	220	22,000	88,000	440,000	9,240,000	17,600,000	22,660,000
Reduction	95	9,500	38,000	1,900,000	3,990,000	7,600,000	9,785,000

[a]Estimated methane emission values are from Joshi et al. (2013) cited in Singh et al. (2009).

On the other hand, water application is also reduced with adoption of DSR. Agricultural intensification in the normal rainfall season can lead to additional benefits to the region/district. Adoption of DSR in the district has reduced the water demand by 480 Mm^3. Interpreting it at project level, NSP provides 7,465 Mm^3 water on average to a command of 0.89 Mha. Paddy, cotton, chillies and irrigated dry crops are grown in the command area (GoAP 2009). Paddy is grown in 0.26 Mha to 0.40 Mha depending on water availability. The transplantation of rice requires about 13,510 m^3/ha and DSR 11,038 m^3/ha (average of 2010–2014 data). Adapting to DSR under the command area by 50% of the minimum area (i.e., 0.13 Mha) can further increase the area by 29,000 ha. Palanisami et al. (2014) also analysed the optimal allocation of land and water for NSP by using multi-goal linear programming to maximize the paddy production, farmers' income and minimize water use with technology adoption. The authors also concluded that DSR reduces water use (20%) without any variation in production. Adoption of DSR is expected to increase during water stress years at the mid- (2021–2050) and end-century (2071–2098) periods.

According to the study, stakeholder integration in upscaling the adaptation practices is needed. Dissemination of the scientific information through different actors and extension methods was greatly experienced in upscaling. The cluster level or system level adoption of the DSR in the canal command areas can help in regulating the water resources and reduce the scarcity.

CONCLUSION AND RECOMMENDATIONS

DSR is efficient in terms of reducing climate change impacts, water use, improving yield (1–6 qt/ha) and better returns to the farmer. Land levelling, weed control and heavy rains during sowing are the major constraints in adoption of DSR. Nonetheless, adoption of DSR has increased from 0.04 to 64% of the rice area in the study district. As a result, additional returns of INR 1,663 million were achieved during 2015 by reducing fuel consumption (6,788 metric tons of CO_2 emissions) and methane emissions in the region. Farmers in Guntur district, especially in the tail-end of the canals are increasingly adopting DSR. This clearly shows farmers are adapting to uncertain monsoon conditions, shortage of labour, and irregular irrigation and water availability. Stakeholder participation in the study showed that it provided an opportunity to the members to contribute knowledge in their respective fields, work towards a common goal with clearly defined roles and responsibilities, articulating problems, finding solutions, exploiting the synergies of working in groups, and sharing the lessons learnt. DSR can be recommended in many parts of Andhra Pradesh and India suffering from delayed and uncertain monsoons and during reduced water release from irrigation projects. Promotion of the practice as an alternative to traditional rice at a wider scale requires more training, capacity building and awareness of farmers. Close cooperation between the scientific community, line departments and farmers also helps in upscaling the technology.

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First received 31 August 2017; accepted in revised form 6 February 2018. Available online 16 March 2018