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AGRONOMIC AND ECONOMIC IMPACTS OF DIRECT SEEDED RICE IN PUNJAB

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ABSTRACT

Labour scarcity, increasing labour costs and declining ground water table have forced farmers in Indian Punjab to find an alternative to resource intensive puddled transplanted rice (PTR). Dry-seeded rice (DSR) was introduced in 2009-10 to address these problems. The impact analysis of this new technology was undertaken by using a comprehensive questionnaire during 2013 through a field survey of farmers who had adopted DSR during 2009 to 2012 in 21 villages in three districts (Bathinda, Faridkot, Sri Muktsar Sahib). The number of farmers who had adopted DSR increased from 10 in 2009 to 211 in 2012; over this time, 11% of these farmers had shifted completely to DSR. The adoption rate of DSR was higher for coarse rice than basmati rice, and adoption was the highest among farmers with medium and large landholding. DSR saved 14 person-days/ha and 18 to 20% irrigation water compared to PTR. To begin with DSR had 2 to 5% yield penalty as compared to PTR. However, as farmers became knowledgeable about DSR especially in sowing and weed control techniques, yield penalty was overcome within one to two years. The productivity of succeeding wheat crop was 5% higher when it was sequenced with DSR than after PTR, thereby increasing higher net returns. The total net returns from DSR-wheat system exceeded PTR-wheat system by INR 5050 to 8100/ha. The results of this survey are consistent with experimental data. Further improvements in planting machinery, weed management practices, and enhancement of grower skills through training programs were identified as the key areas for accelerating the adoption of this new production technology at scale.

Key words: Direct-seeded rice, Labour saving, Puddle transplanted rice, System productivity, Water saving, Wheat

Rice in the Indo-Gangetic Plains (IGP) is principally grown by hand-transplanting in puddled (wet cultivation) fields. Puddling has been shown to degrade soil structure and requires large amount of water and energy. This system of rice production worked well for many years when farm labour was readily available and affordable. However, Indian economy has gone through a major transformation over the last decade. Over this period, farm labour has been moving to work in industries where wages and work conditions are superior to the traditional work on farms. This shift in labour has been reflected in rapid increase in farm labour wages, which has squeezed profitability of rice production in the region. The northern IGP has also seen a rapid decline in ground water table as a result of over-exploitation of underground aquifers, which has become a serious issue affecting the sustainability of the irrigated agriculture. This trend of escalating labour costs and decline in ground water table have driven the need to develop rice production systems that conserve labour, energy and water.

Some of the recent public policies have further aggravated labour costs in states such as Punjab. The agriculture sector in Punjab is heavily dependent on migrant labour. With the implementation of Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS) by Indian government in 2005 (Anonymous, 2005), cost of manual transplanting of paddy has increased from INR 1500 in 2005 to more than INR 5000 per ha in 2012 (Gill *et al*., 2013). Dry-seeded rice (DSR) was introduced in Punjab in 2009-2010, as an alternative to conventional manual puddled transplanted rice (PTR), for saving labour, water and energy costs. Some rice growers in Punjab had started experimenting with DSR on a small scale in 2009; before this there was no drill sown DSR in Punjab. In 2014, the DSR was grown on 115,000 ha in Punjab (Anonymous, 2014). This rapid adoption of DSR in Punjab is a clear evidence of conservation agriculture (CA) breakthrough in Punjab. The state government has also been encouraging efforts to scale up the adoption of resource conservation technologies such as DSR. This has resulted in effective subsidies for farmers for the purchase of seed drills, which is playing an important role in the adoption of CA in this region.

The objectives of this farmer survey were to undertake agronomic and economic impact of new technology through a survey of local farmers and to make suitable recommendations for further accelerated adoption of this technology.

MATERIALS AND METHODS

The Punjab state in India is comprised of 22 districts and out of these, three districts namely Bathinda, Faridkot and Sri Muktsar Sahib (Muktsar) were randomly selected for undertaking the agronomic and economic impact assessment of dry-seeded rice technology. Bathinda and Muktsar

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Table 1. Farm characteristics of the surveyed districts in Punjab.

District	Villages	Total cultivated area (ha)	Farmers under different categories (No.)				
			Small (≤ 2 ha)	Medium (2-10ha)	Large (>10ha)	Total	Sampled DSR farmers
Bathinda	Mehraj, Dhelwa Kalan, LehraMahobat, Khemuana, Gill Kalan, Sema Kalan, Nathana	12800	1419	1348	308	3075	93
Faridkot	Sibian, PunjGraai Kalan, BirSikhan Wala , Fide Khurd, Wander Jatana, Hari Naw, Chand Baja, Mandala, Dhurkot	9117	1219	1197	504	2920	77
Muktsar	Kaoni, Dhulkot, Guri Shangar, Bhullar, Thandewala	7892	710	862	328	1900	41
Total		29809	3348	3407	1140	7895	211

districts represent western-plain, arid zone; major cropping systems are rice-wheat and cotton-wheat. Faridkot district represents northern plain, semi-arid zone; major cropping system is rice-wheat. All farmers selected for the survey (n=211) in 21 selected villages had already adopted DSR (Table 1). A comprehensive questionnaire was prepared and data were collected in 2013 by personal interview method. In the sampled villages, paddy-wheat crop rotation was adopted by 75% of the sampled farmers; followed by paddy/cotton-wheat (11 %) and rest of the farmers (14%) practiced others crop rotations. All farmers in this study irrigated their fields with tube-wells (bore wells), using underground water, and with canal water. The data on irrigation water, human labour and cost of cultivation was collected in the survey. Cost of cultivation of DSR and PTR was estimated, without taking into account the rental value of land. Gross returns were calculated by taking into account the minimum support price for rice and wheat offered by the Government of India (GOI). Returns over variable costs were calculated for assessing the economic viability of this technology.

RESULTS AND DISCUSSION

DSR adoption trends

Only 10 farmers in Punjab cultivated DSR on a small scale (<1 ha each) in 2009, which increased to 211 in 2012 (Table 2).Farmers adopting DSR increased from 0.1% in 2009 to 0.5% in 2010, 1.2% in 2011 and to 2.7% in 2012. The trend for farmer adoption of DSR was similar across the three districts in 2011, and in 2012 the highest increase was recorded in Bathinda. Within three years, 2010-12, the number of farmers practicing DSR increased more than five-fold. The area under DSR increased from 1.2 to 2.0% of the total rice area from 2010 to 2012; in 2012, Faridkot had the highest area under DSR (Table 2). Faridkot and Muktsar districts have higher percentage of farmers with large landholding (17%) which could be the reason for greater adoption of DSR in these districts compared to Bathinda which has a lower percentage of farmers with large land holding (10%). Even though farmers with medium sized landholding represent 43% of total farmer population, they accounted for more than 63% area under DSR. Similarly, there are 14% farmers in large landholding category but they accounted for 28% area under DSR in three districts. It could be argued that adoption of DSR using seed drills would be more affordable for farmers with large landholding. The farmers with small landholding account for 42% of total farmers in the study area but only accounted for 8.2% of the area under DSR (Table 3). Greater capacity of the farmers with medium to large landholdings to take and bear risk of new technology could be the major reasons for higher DSR adoption among these farmers.

Previous research has shown that correct sowing depth, optimum seed rate, use of rice seed drills, maintenance of moisture in the field and effective weed management are important factors for successful DSR production (Gill *et al.*, 2013). It is common for new adopters to proceed with caution. Most farmers initially experimented with DSR on a small scale (<1 ha) and then gradually increased the area as they gained confidence. For example, one farmer in Bathinda started DSR in 2009 with 0.8 ha (4% area under rice) but in 2012, 88% of the total rice area (22.5 ha) was under DSR[2]. The survey also showed that some adopters of DSR (11% or

Table 2. DSR adoption trends based on number of farmers and area under DSR from 2009-2012 in Punjab.

District	Number of DSR farmers				Area under DSR (ha)			
	2009	2010	2011	2012	2009	2010	2011	2012
Bathinda	6(0.2)[x]	21(0.7)	34(1.1)	93(3.0)	30 (0.2)[Y]	65 (0.5)	92 (0.7)	188 (1.4)
Faridkot	3(0.1)	11(0.4)	33(1.1)	77(2.6)	33 (0.4)	171 (1.9)	220 (2.4)	250 (2.7)
Muktsar	1(0.1)	11(0.6)	21(1.1)	41(2.2)	4 (0.1)	113 (1.4)	126 (1.6)	145 (1.8)
Total	10(0.1)	43(0.5)	98(1.2)	211(2.7)	67 (0.2)	348 (1.2)	438 (1.5)	582 (1.9)

[x]Parentheses indicate percentage of total number of farmers; [y]Parentheses indicate percentage of total cultivated area (ha)

Table 3. DSR adoption trends among different category farmers in Punjab (2012).

Name of district	Number of DSR farmers (of different categories)			
	Small (≤ 2 ha)	Medium (2-10ha)	Large (>10ha)	Total farmers
Bathinda	7 (0.5)*	60 (4.4)	26 (8.4)	93(3.0)
Faridkot	7 (0.6)	48 (4.0)	22 (4.4)	77 (2.6)
Muktsar	0 (0)	22 (8)	19 (3)	41 (2)
Total	14 (0.4)	130 (3.8)	67 (6.0)	211 (2.7)

*Parentheses are percentage of total number of farmers in a district

23 farmers) shifted completely to DSR within four years of initial adoption. DSR was being used by the farmers for the production of coarse grain rice (56%), basmati rice (37%) and both rice types (7%) (data not presented). These results are broadly in line with the relative area under coarse grain and basmati rice in Punjab.

Sowing time

The recommended sowing time for dry seeded rice falls between 1 to 15 June for coarse rice and 15 to 30 June for basmati rice. For coarse rice, 50, 26, 67% farmers adopted timely sowing in Bathinda, Faridkot and Muktsar districts, respectively, and in case of basmati the respective figures were 8, 33 and 55%. On an average, 43% farmers followed recommended sowing time for coarse grain rice while 57% planted DSR from 20 to 30 May, which is earlier than the recommended sowing time (Table 4). For basmati rice, only 28% farmers followed the recommend sowing time while72% started sowing in the last week of May which is earlier than the recommended time (Table 4). Farmers achieved higher yields (6%) from early seeding of coarse grain rice (7.6 t/ha) than the recommended sowing time (7.2 t/ha); however, early sowing did not consistently increase productivity of basmati rice. In Faridkot, farmers achieved 6% higher basmati yield with early sowing but there was no benefit of early sowing in Muktsar and Bathinda. The state government has set 15 June as the start of puddle transplanting date hence the farmers tend to complete the direct seeding of both coarse grain and basmati rice before this date to avoid conflict with paddy transplanting. In this context, the need based availability of electricity and canal irrigation supply during this period would promote the area under direct sowing.

According to the current recommendation, farmers should be growing short duration rice varieties because of potential savings in irrigation water. However, 85% of the survey respondents were growing long duration varieties (>158d) in dry seeded systems in order to achieve higher productivity and profit. In Bathinda, 100% of the coarse grain rice area and in Faridkot and Muktsar districts 80% rice area was allocated to long duration varieties (Table 5). The farmers were using the same varieties for dry-seeding as they have been using under puddle transplanting, as they had high level of confidence in these varieties. Adoption of these long duration varieties was also the main reason for the earlier than recommended sowing time reported in the survey. If these long duration varieties are sown later in the first week of June, they not only produce lower grain yield but also delay the sowing of succeeding wheat crop leading to lower yields. Obviously, farmers are unwilling to sacrifice rice yield to make some savings in irrigation by delayed sowing. This poses a challenge to rice breeders to develop shorter duration varieties with similar yield potential as the current longer duration varieties. Availability of such high yielding varieties will allow the farmers to delay rice sowing to save irrigation water without sacrificing potential yield and profit. In Muktsar, however, the early sowing did not increase the yield of rice, as this district has a shallow water table (<10m) compared to other two districts where water table is much deeper (>40m). In Muktsar, >67% rice area is currently under basmati rice compared to 14% in Faridkot and 29% in Bathinda. Basmati rice is well known to have a lower yield potential than coarse grain rice and tends to not benefit from early sowing. Furthermore, early sowing can also diminish grain fragrance and quality of basmati rice.

Table 4. Paddy productivity at different direct sowing dates in Punjab in 2012.

District	Paddy productivity (t/ha)				
	Direct seeded rice		Direct seeded basmati rice		
	Early sowing (15-31 May)	Timely sowing (1-15 June)	Early sowing		Timely sowing
			15-31 May	1-15 June	16-30 June
Bathinda	7.43(29)*	7.19(28)	4.34(17)*	4.41(16)	4.42(3)
Faridkot	7.81(39)	6.97(14)	-	4.49(16)	4.23(8)
Muktsar	7.10(7)	7.31(14)	-	4.21(9)	4.40(11)
Mean	7.60(75)	7.17(56)	4.34(17)	4.40(41)	4.34(22)

*Parentheses: number of farmers

Therefore, basmati rice presents an excellent opportunity for Muktsar rice farmers to adopt DSR to achieve labour and water savings without sacrificing yield.

Very recently, Punjab has released high yielding short duration varieties of rice (PR 126, 125d and PR 124, 135d) and of basmati (Pusa basmati 1509, 105d) (Anonymous, 2017), which have yield potential similar to the existing long duration varieties. These varieties could fit well into the currently recommended sowing window (June) for direct seeding of rice. This new short duration high yielding rice varieties have been approved for farmers' field adaptive research trials in 2017 and are expected to be recommended for dry-seeding of rice in the state. The area under long duration rice varieties in the state has already reduced from >40% in 2012 to <20% in 2016, indicating that farmers are willing to accept a short duration variety provided it gives yield similar to the long duration ones. The recent legal restrictions imposed on burning of crop residues are further expected to increase the area under short duration rice varieties as farmers will need more time to manage rice residues before sowing wheat.

In case of coarse dry seeded rice, 63% farmers reported 10 to 20% reduction in irrigation water, 29 to 36% farmers reported 20 to 30% and the rest of farmers reported a saving of >30% in DSR compared to PTR. Averaged over coarse grain rice and basmati, farmers practicing dry-seeding saved 18 to 20% irrigation water compared to PTR (Table 6). Previous research in this region has shown that it was possible to reduce the amount of irrigation water by 15 to 20% under DSR without reducing rice grain yield relative to the traditional PTR (Yadav *et al*., 2011; Bhullar *et al*., 2016). Therefore, the results of this farmer survey are consistent with previous research findings on irrigation water savings in dry direct seeded rice. Farmer respondents in the survey indicated that the water table in the region had declined by >3 feet (ft)/year during the period 2002 to 2012 (data not shown). This ongoing decline in the ground water table is a serious concern for the sustainability of irrigated agriculture in this region. Therefore, all initiatives aimed at reducing irrigation use, including adoption of DSR, need to be encouraged.

Table 6. Water saving under DSR compared to PTR in Punjab in 2012.

Type of rice	Irrigation water reduction under DSR compared to PTR (% farmers)*		
	10-20%	20-30%	30-40%
Coarse rice	61.8	29.2	8.9
Basmati rice	63.3	36.6	-

*Combined data for the three districts

Farmer respondents in the survey reported that dry-seeding of drill sown rice saved 14 person-days/ha compared to PTR; 70% of the farmers reported that DSR saved 10 to15 person-days, 25% farmers reported 15 to 20 person-days and 5% reported saving 20 to25 person-days/ha (Table 7). As mentioned already, labour scarcity in agriculture has been one of the major drivers for shift towards DSR. Rapid increase in area under dry-seeded rice from only a few ha in 2010 to >115,000 ha in 2014 (Anonymous, 2014) indicates that Punjab is going through a major transformation in rice production technology.

Table 7. Labour saving under DSR compared to PTR in Punjab in 2012.

Labour saving under DSR compared to PTR (No. of person-days/ ha)*	Farmers (%)
10-15	70.2
15-20	25.2
20-25	4.7

*Combined data for the three districts

Weed management

About 86% farmers in Faridkot district used recommended pre-mergence herbicide, compared to only 15% in case of Bathinda and Muktsar districts (Table 8). The use of pre-emergence herbicide application is considered critical for weed management in DSR. It seems many early adopters of DSR omitted pre-emergence herbicide application, which could lead to serious weed management issues. In case of post-emergence herbicide, >95% farmers used recommended herbicide in Muktsar and Faridkot but the figure was much lower (67%) in Bathinda. The heavy reliance of farmers on un-recommended herbicides, oxadiargyl in Bathinda, and butachlor and pyrazosulfuron in Muktsar as pre-emergence, and fenoxaprop without safener as post-emergence in all the districts resulted in poor weed control, crop toxicity or both. Sub-optimal pre-emergence and post-emergence weed control practices identified by this survey highlights the need for focussed training programs for farmers on changes in weed flora, herbicides and their applications techniques, and integration of different weed management strategies in DSR systems so that weeds can be managed effectively. Adoption of correct herbicide options will also reduce the need for additional hand weeding in DSR.

Table 8. Adoption trends for use of recommended herbicides in DSR in Punjab.

District	Use of recommended herbicides (% farmers)			
	Pre-emergence		Post-emergence	
	2009	2012	2009	2012
Bathinda	17 (1)*	14 (13)	67 (4)	68 (63)
Faridkot	100 (3)	86 (67)	100 (3)	94 (72)
Muktsar	100 (1)	15 (6)	100 (1)	100 (41)

*Parentheses indicate number of farmers

Adoption of DSR rapidly changed the weed flora from typical rice- to non-rice weeds especially to aerobic grass weeds. Weed spectrum changed from *Echinochloa crus-galli* and *E. colonum* dominance to *Dactyloctenium aegyptium, Leptochloa chinensis* among grass weeds, and from annual

Table 9. Shift in weed flora under DSR in Punjab.

Year	Weed flora composition (%)*						
	***Echino-chloa* spp.**	***Dactyloctenium aegyptium***	***Leptochloa chinensis***	***Cyperus rotundus***	***Cyperus iria***	**Broad-leaf weeds**	**Weed free**
2009	55	0	0	0	11	11	23
2012	30	50	5	10	0	5	0

*Combined data for the three districts; *Echinochloa* spp. include- *E. crus-galli & E. colonum;* Broadleaf weeds include-*Digera arvensis, Caesulia axillaris, Trianthema portulacastrum, Eclipta alba*

sedges *Cyperus iria* and *C. difformis* to perennial *C. rotundus* (Table 9). The infestation of typical rice weeds *Echinochloa* spp. decreased from 55 to 30%, *C. iria* from 11 to 0%, and broadleaf weeds from 11 to 5% during 2009 to 2012. During the same period, the infestation of *D. aegyptium* increased from 0 to 50%, *L. chinensis* from 0 to 5%, and *C. rotundus* from 0 to 10%. The shift form typical rice to aerobic weeds under DSR was due to lack of deep flooding, which prevents aerobic rice weeds from establishing in PTR field. Once farmers adopt DSR and switch to alternate wetting and drying cycles of irrigation, many aerobic weeds infest DSR. Such weeds tend to be highly competitive and need to be controlled effectively. Herbicides recommended for PTR could be less effective in DSR which can lead to a build-up in the population of aerobic weeds over time. New herbicides molecules like fenoxaprop with safener and cyhalofop for control of aerobic grass weeds, and metsulfuron plus chlorimuron for control of perennial sedges and broadleaf weeds have now been introduced for DSR fields (Gill *et al*., 2013).Use of these new herbicides along with bispyribac (mainly against *Echinochloa* spp.) can be used to achieve excellent control of diverse weed flora encountered in DSR.

DSR agronomic management

There have been significant changes in sowing method used for drill sown dry-seeded rice over the years. In Muktsar, 67% farmers adopted dry-bed method compared to 57% in Faridkot and 47% in Bathinda (Table 10) indicating farmers' preference for DSR methods vary with their soil type and even weed flora. Pre-sowing irrigation used in the moist-bed method helps in timely application of pre-emergence herbicide and it also acts as stale seedbed, hence reduces weed pressure as compared to dry-bed in which herbicide application is often delayed (based on soil texture). The average seed rate had declined slightly (3-6%) over the period of 2009 to 2012 (Table 10) due to improvements in the quality of seed drills and farmers' skills in the management of DSR.

Paddy productivity

In general, the farmers recorded small yield penalty of 2 to 5% in first year of DSR adoption in all three districts. However, after one to two years of adoption and experience, DSR yields were similar to or slightly higher than PTR, which highlighted the importance of skill development in achieving optimum yield in DSR. Interestingly, farmers who adopted DSR in Muktsar in 2010 continued to achieve 5-7% higher yield from DSR than PTR indicating that if all required knowledge is gained at the outset then DSR could provide similar productivity to PTR from the first year itself. DSR has also been shown to provide similar yield potential to that of PTR in first year itself in other environments (Mitchell *et al.*, 2004; Ali *et al.*, 2007). In general, the DSR yield varied between (-) 2.5 to (+) 6% compared to PTR after 2 years of adoption; the trend was similar across the districts (Table 11). Similar trends in productivity were also recorded for basmati rice (Table 12). The survey results clearly indicated that DSR has the potential to reap productivity levels similar to PTR if farmers can be trained well. Proper knowledge, awareness and technical skills enhance adoption of DSR.

Economic analysis

The total variable costs of coarse rice were INR 6436/ha lower in DSR compared to PTR (Table 13). Amongst variable cost components, in PTR the planting operation accounted for 40% of total variable cost while it was only 19% in DSR. Such large differences between the two systems directly related to labour savings in DSR at the time of planting, which has been a major driver in the adoption of this new technology in the state. The other major variable cost

Table 10. Changes in sowing method and seed rate in DSR over time in Punjab.

District	Percent farmers					
	Sowing method				Seed rate (kg/ha)	
	Dry-bed		Moist-bed			
	2009	2012	2009	2012	2009	2012
Bathinda	83	47	17	53	19.2	18.2
Faridkot	67	57	33	43	19.2	18.7
Muktsar	0	63	100	37	20.0	18.7

Table 11. Comparison of paddy productivity of dry- seeded (DSR) and puddle transplanted (PTR) rice from 2009-2012 in Punjab.

District	Paddy productivity (t/ha)							
	Year of DSR adoption							
	2009		2010		2011		2012	
	DSR	PTR	DSR	PTR	DSR	PTR	DSR	PTR
Bathinda	7.7 (8.3)*	8.1 (8.0)	7.6 (7.9)	8.0 (7.9)	7.5 (7.8)	7.9 (8.0)	7.5	7.9
Faridkot	7.0 (7.5)	-	7.9 (8.4)	7.9 (8.3)	7.5 (8.1)	7.7 (7.9)	7.5	7.7
Muktsar	4.2 (8.5)	8.0 (8.0)	8.5 (8.3)	7.9 (7.9)	-	-	8.2	8.4

*Parentheses indicate paddy productivity in 2012; In 2009, higher weed pressure in Muktsar (one farmer) significantly reduced yield

Table 12. Comparison of basmati productivity of dry-seeded basmati (DSBR) and puddle transplanted basmati (PTBR) rice from 2009-2012 in Punjab.

District	Paddy productivity (t/ha)							
	Year of DSBR adoption							
	2009		2010		2011		2012	
	DSBR	PTBR	DSBR	PTBR	DSBR	PTBR	DSBR	PTBR
Bathinda	4.2 (4.8)*	4.6 (4.9)	4.2 (4.4)	4.6 (4.8)	4.3 (4.4)	5.0 (5.3)	4.6	4.7
Faridkot	4.2 (4.9)	4.7 (4.7)	4.3 (4.4)	4.5 (4.7)	4.8 (4.8)	5.1 (5.4)	4.5	5.2
Muktsar	-	-	5.2 (5.1)	5.0 (4.8)	5.1 (5.1)	5.1 (4.9)	5.0	4.9

*Parentheses indicate paddy productivity in 2012

Table 13. Economic analysis of dry-seeded and puddle transplanted rice in Punjab (2012).

Particulars*	Coarse rice		Basmati rice	
	DSR	PTR	DSBR	PTBR
Cost of cultivation (INR/ha)*	16124	22560	15574	21523
Paddy yield (t/ha)	7.487	7.675	4.393	4.640
Gross returns (INR/ha)*	95834	98240	124546	129418
Net returns (INR/ha)*	79710	75680	108973	107895

* Cost of cultivation includes only variable costs. Gross and net returns are over variable costs only; the land rental value has not been included in the cost of cultivation

components such as inputs and harvesting cost were similar in DSR and PTR. In case of basmati rice, the total variable costs were INR 5949/ha lower for dry-seeding compared to manual transplanting. Here also, the planting accounted for 44 and 26% share of total variable costs in PTR and DSR, respectively. The DSR recorded higher net returns than PTR, both in coarse and basmati rice. The higher economic returns and labour savings in DSR as compared to PTR have also been reported earlier (Gill *et al.*, 2013).

Researchers' and farmers' experience shows that the productivity of wheat grown after DSR is greater than wheat grown after PTR. This beneficial impact of DSR on wheat was also reflected in our survey results (Table 14). The surveyed farmers reported 4.8% higher (0.3 t/ha) wheat productivity in sequence with DSR as compared to PTR. Greater root development of wheat plants, owing to less water stagnation and yellowing in wheat after first irrigation, following DSR has been cited as one possible factor for higher wheat productivity compared to wheat sown after PTR (Aggarwal *et al.*, 1995; Kumar *et al.*, 2011).

The survey results clearly showed that adoption of DSR results in similar or higher productivity of succeeding wheat crop compared to the conventional puddle transplanted rice. The total returns from DSR-wheat cropping sequence were INR 5050 to 8100/ha higher than PTR-wheat system.

Table 14. Impact of DSR on productivity of succeeding wheat in Punjab (2012-13).

District	Wheat productivity (t/ha)	
	After DSR	After PTR
Bathinda	5.94 (93)*	5.61 (93)
Faridkot	5.92 (77)	5.63 (77)
Muktsar	5.36 (41)	5.31 (41)
Average of 3 districts	5.82 (211)	5.56 (211)
Average net returns over variable costs (INR/ha)	45783	42273

*Parentheses are number of farmers

Farmers' perceptions of DSR

All surveyed farmers reported that critical care during first month had been the major contributor towards success

Table 15. Farmers' perception of DSR.

District	Farmer perception (% farmers)							
	Laboursaving	Water saving	Timely sowing	Less hectic schedule during sowing	Machinery depreciation	Paddy productivity		
			Yes	Yes	Low	Low	Constant	High
Bathinda	100	100	100	100	100	88	0	12
Faridkot	83	93	100	100	100	30	36	34
Muktsar	93	97	100	100	100	61	17	22
Mean	93	97	100	100	100	62	16	22

of DSR. One-third farmers highlighted the importance of management of iron deficiency and 80% raised the need for effective weed management as the key issues for the success of DSR (data not presented). All surveyed farmers were convinced that DSR helps in timely sowing of crops, reduces machinery depreciation and provides less hectic personnel schedule during sowing, and saves labour and water (> 90% farmers) as compared to PTR. Somewhat lower DSR productivity was also one of the perceptions among 62% of surveyed farmers particularly in Bathinda and Muktsar districts (Table 15).Farmers raised importance of new rice varieties (73%), herbicides (50%) and machinery (10%), and bridging up knowledge gaps (67%) and subsidy (55%) for faster adoption and spread of this technology.

It can be concluded from this farmers' field survey that the DSR technology has been readily accepted by the growers in Punjab. DSR has the potential to provide similar productivity and equal or greater economic returns compared to conventional practice PTR, provided the growers are provided required level of knowledge and training. The labour and water savings offered by DSR have been the major drivers in the adoption of new technology. The development of shorter duration-high yielding varieties with greater adaptation for dry-seeding, further improvements in planting machinery, weed management practices and enhancement of grower skills through trainings were identified as the key areas for achieving even faster adoption and spread of this technology.

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Authors' contribution

Conceptualization of research work and designing of experiments (MSB, SS, SK, GG); Execution of field/lab experiments and data collection (MSB, SK); Analysis of data and interpretation (MSB, SS, SK); Preparation of manuscript (MSB, SS, SK, GG)

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