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Direct Seeded Rice: Prospects, Problems/ Constraints and Researchable Issues in India

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ABSTRACT

Transplanting after repeated puddling is the conventional method of rice (*Oryza sativa*) growing which is not only intensive water user but also cumbersome and laborious. Different problems like lowering water table, scarcity of labour during peak periods, deteriorating soil health demands some alternative establishment method to sustain productivity of rice as well as natural resources. Direct seeded rice (DSR), probably the oldest method of crop establishment, is gaining popularity because of its low-input demand. It offers certain advantages viz., it saves labour, requires less water, less drudgery, early crop maturity, low production cost, better soil physical conditions for following crops and less methane emission, provides better option to be the best fit in different cropping systems. Comparative yields in DSR can be obtained by adopting various cultural practices viz., selection of suitable cultivars, proper sowing time, optimum seed rate, proper weed and water management. It can also be stated that soil problems related to rice and following crops can be solved with direct seeding. There are several constraints associated with shift from PTR to DSR, such as high weed infestation, evolution of weedy rice, increase in soil borne pathogens (nematodes), nutrient disorders, poor crop establishment, lodging, incidence of blast, brown leaf spot etc. By overcoming these constraints DSR can prove to be a very promising, technically and economically feasible alternative to PTR. The potential benefits and constraints associated with adoption of DSR are discussed in this paper.

Keywords: Aerobic rice, Economics, Green house gas emmissions, Resource conservation, Water saving, Weeds.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world, and staple food for more than 50% of the global population. Being the major source of food after wheat, it meets 43 % of calorie requirement of more than two third of the Indian population. In South Asia, rice was cultivated on 60 million hectares (m ha), and production was slightly above 225 million hectares (m t) of paddy, accounting for 37.5 and 32% of global area and production in 2013, respectively[60]. In India, it is grown on an area of about 43.5 m ha with a total production of 105.5 m t and productivity of 2.4 t /ha during 2014-15[2]. In Punjab, it occupied 2.89 m ha with total production of 11.11 m t and productivity of 3.8 t /ha during 2014-15[3]. It shows Punjab has more productivity/ha than national level even though state is facing the scarcity of irrigation water and deterioration of soil health.

Increasing water scarcity, water loving nature of rice cultivation and increasing labour wages triggers the search for such alternative crop establishment methods which can increase water productivity. Direct seeded rice (DSR) is the only viable option to reduce the unproductive water flows. DSR refers to the process of establishing a rice crop from seeds sown in the field rather than by transplanting seedlings from the nursery. It has been recognized as the principal method of rice establishment since 1950's in developing countries[70]. Direct seeding is can be done by sowing of pre-germinated seed into a puddled soil (wet seeding) or standing water (water seeding) or prepared seedbed (dry seeding). Improved short duration and high yielding varieties, nutrient and weed management techniques encouraged the farmers to shift from traditional sytem of transplanting to DSR culture. Direct seeding offers certain advantages like saving irrigation water, labour, energy, time, reduces emission of greenhouse-gases, better growth of succeeding crops, etc.

In the conventional puddled transplanting system (PTR), large quantity of irrigation water is used for puddling which breaks capillary pores, destroys soil aggregates and results in formation of hard pan, creating problems for the establishment and growth of succeding crops. Since the water resources (both surface and underground) are shrinking day by day[30] and the profit margins are decreasing in PTR mainly because of high labour cost and water requirement[20, 71], so, switching over from PTR to DSR cultivation took place. PTR has higher labour demand as compared to DSR as labour is required for uprooting seedlings from the nursery, field puddling and transplanting of the seedlings. Moreover, in case of low labour wages along with adequate water availability prefer transplanting, whereas in alternate case of high wages and low water availability prefer DSR[69]. The reasons for adoption of DSR, types of direct seeding, comparison of DSR and PTR, potential benefits, constraints and possible solutions are discussed in this paper.

Why DSR?

The various reasons responsible for the shift from PTR to DSR are discussed as follows:

Major reasons

Water scarcity

Water -guzzling puddled transplanted rice

Conventional rice establishment system requires substantial amount of water. It has been reported that water up to 5000 litres is used to produce 1 kg of rough rice[14]. Rice is a major freshwater user and consumes about 50% of total irrigation water used in Asia[7]. and accounts for about 24-30% of the withdrawal of world total freshwater and 34-43% of the world's irrigation water[15].

Increasing demand and competition of water from non-agricultural sector

The share of water for agriculture is declining very fast because of the increasing population, lowering of the water table, declining water quality, inefficient irrigation systems, competition with non-agricultural sectors. At present, irrigated agriculture accounts for 70 and 90% of total freshwater withdrawal globally and in Asia, respectively[61]. In the major rice-growing Asian countries, per capita water availability reduced by 34-76% between 1950 and 2005, and is likely to decline by 18-88% by 2050. In Asia, the share of water in agriculture declined from 98% in 1900 to 80% in 2000, and is likely to further decline to 72 % by 2020[54].

During the present scenario of ground water utilization, India is the largest groundwater utilizer (260 km^3/year) in the whole world (Table1). In case of Punjab, according to the Central Ground Water Board and Development of Irrigation, Punjab, the number of overexploited blocks have increased from 63 in 1992 to 107 in 2010[18].

Water wise-direct seeding practice

The establishment technologies, which inherently require less water, and are more efficient in water use are demanded by the grim water scenario in agriculture together with the highly inefficient traditional transplanting system. DSR being a water wise technology, provides the solution. Both methods of DSR (Dry and Wet) are more water efficient, and have an advantage over PTR[98]. However, with increasing shortage of water, Dry-DSR with mimimum or zero tillage (ZT) further enhances the benefits of this technology by saving labour.

The rising cost and scarcity of labour at peak periods

DSR saves labour as it avoids nursey raising, uprooting seedlings, transplanting as well as puddling. Further the demand for labour is spread out over a longer period in DSR as compared to PTR, where more labour is required at the time of transplanting thus resulting in its shortage. Rapid economic growth in Asia has increased the demand for labour in non-agricultural sectors resulting in less labour availability for agriculture. In Asia, labour forces in agriculture are declining at 0.1-0.4%, with an average of 0.2% per year[24].

Other reasons

Adverse effects of puddling

Puddling breaks capillary pores, destroys soil aggregates, disperses fine clay particles and form a hard pan at shallow depth. It is beneficial for rice as it control weeds, improves availability water and nutrient, facilitates transplanting and results in quick establishment of seedlings[25]. Although puddling is known to be beneficial for growing rice, it can adversely affect the growth and yield of subsequent upland crops because of its adverse effects on soil physical properties, which includes poor soil structure, sub-optimal permeability in the lower layers and soil compaction[35]. The harmful effects of puddling on ensuing crops increased interest in shifting from CT-PTR to Dry-DSR on ploughed soil (No puddling) or in ZT conditions, where an upland crop is grown after rice[39, 55]. This is especially relevant to the rice-wheat system in which land goes through wetting and drying phenomenon. It, therefore, becomes imperative to identify alternative establishment method to puddling especially in those regions where water is becoming scarce, and an upland crop is grown after rice.

Rising interest in conservation agriculture

Conservation agriculture (CA) involves zero tillage (ZT) or reduced tillage (RT) followed by row seeding using a drill. Conservation tillage, when utilizes crop residue as mulch with improved crop and resource management methods, is termed CA or integrated crop and resource management (ICRM)[55]. Declining/stagnating crop and factor productivity and a deteriorating resource base in cereal systems like rice-wheat have led to the promotion of conservation tillage-based agriculture. Now, the efforts are being made to develop ZT rice followed by ZT wheat- commonly referred to as “double zero tillage “ to realize the benefits of ZT in toto.

Best fit in cropping system

Besides the savings in labor and water, economic benefits brought out by DSR through the integration of an additional crop (crop intensification) are another reason for the rapid adoption of DSR. Earlier maturity of DSR as compared to PTR fits this crop well in different cropping systems[36].

Different methods of direct seeding

Rice can be established by three principal methods: transplanting, dry-DSR and wet- DSR. These methods differ from others either in land preparation (tillage) or crop establishment method or in both. Transplanting is the dominant crop

Table 1: Trends of groundwater utilization over years

Country	Groundwater withdrawal (km^3 /year)							
	1940	1950	1960	1970	1980	1990	2000	2010
US	60	70	80	90	100	104	107	107
W.Europe	45	45	44	43	42	41	40	39
Spain	3	4	5	6	8	10	12	14
Mexico	20	23	28	35	42	48	54	58
China	10	12	14	20	35	50	75	90
India	8	12	20	50	100	150	210	260
Pakistan	3	5	8	15	30	45	60	75
Bangladesh	5	9	18	30	45	60	70	80
Sri Lanka	3	3	3	3	4	8	15	25
Vietnam	2	2	2	4	6	8	15	25
Ghana	1	1	1	1	2	2	6	10
South Africa	5	6	7	8	9	12	17	25
Tunisia	8	9	10	11	12	15	30	40

Source: www.irri.org/irric/ssnm.

establishment practice in Asia particularly in tropical part. In this method, the land is puddled and seedlings raised in nursery are transplanted. Dry and wet-seeding, in which seeds are sown directly in the main field instead of transplanting rice seedlings, are commonly referred to as direct seeding. Direct seeding is the oldest method of rice establishment and was shifted with time by transplanting.

Dry DSR

In Dry-DSR, rice is established using several different methods, including (i) broadcasting of dry seeds on unpuddled soil after either ZT or CT (ii) dibbled method in a well-prepared field and (iii) drilling of seeds in rows after CT, minimum tillage (MT) using a power tiller-operated seeder, ZT or raised beds. In case of both CT or ZT, a seed-cum-fertilizer drill is used, which, after land preparation or in ZT conditions, places the fertilizer and drills the seeds[54].

Wet DSR

Wet-DSR involves sowing of pregerminated seeds (radicle 1- 3 mm) on or into puddled soil. When pregerminated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic Wet-DSR. When pregerminated seeds are sown/drilled into puddled soil, the seed environment is mostly anaerobic and this is called as anaerobic Wet-DSR. Wet-DSR under aerobic and anaerobic, seeds can either be broadcasted or sown in-line using a drum seeder[81] or an anaerobic seeder with a furrow opener and closer[6].

Direct-Seeded Rice v/s Transplanted Rice

The performance of different types of direct seeding methods of rice (DSR) as compare with that of conventional puddled transplanted rice (CT-PTR) based on the following criteria :

i. Grain yield
ii. Irrigation water applied and water use efficiency
iii. Labor use
iv. Greenhouse gas (GHG) emissions
v. Economics
vi. Effect on succeeding crops

Grain yield

DSR is both cost and labour-saving technology and similar or even higher yields[40] of DSR can be obtained with good management practices. The higher grain yield of DSR as compared to PTR was obtained mainly because of higher panicle number, higher thousand grain weight and lower sterility percentage[88].

Dry-direct seeding, drum seeding, mechanical transplanting (unpuddled) and manual transplanting (puddled) were compared[32] and the grain yield was significantly higher with drum-seeding followed by dry direct seeding, and mechanical transplanting (unpuddled)(Table 2). Effective tillers per square metre and 1000-grain weight were responsible for the increase in yield.

Comparative yields in DSR can be obtained by adopting various cultural practices viz., selection of suitable cultivars, proper sowing time, optimum seed rate, proper weed and water management. A significantly higher grain yield[37] in direct seeding was observed (4.83t/ha) as compared to transplanting (4.28t /ha), which was mainly attributed by the effective tillers (245) and 1000-grain weight (22.7g) as compared to the transplanted crop and found that the maximum productivity was obtained

Table 2: Effects of rice establishment methods on yield attributes and grain yield

Establishment method	Effective tillers /m^2 (at harvest)	1000 grain weight (g)	Grain yield (t /ha)
Direct seeding (dry bed, aerobic)	361	26.8	7.84
Drum seeding (wet bed unpuddled)	381	27.1	8.11
Mechanical transplanting (unpuddled)	352	26.4	7.75
Manual transplanting(puddled)	332	26.2	7.46
C.D (P= 0.05)	11	0.7	0.38

Source: [32]

when DSR crop was raised on 10 June (5.13 t/ha) (Table 3). A short duration, early maturing cultivar PR 115 was found better than other medium and long-duration varieties.The effect of seed rate, irrigation and weed control methods on grain yield of direct seeded basmati rice was studied[36] and they found that crop with 50 kg /ha seed rate, integrated weed management and irrigation interval at 2 days produced maximum yield, although it was at par with transplanted rice but it was about 20% higher than the transplanted (Table 4).

Irrigation water applied and water use efficiency

Wet seeded rice (WSR) was compared with PTR in Central Luzon, Philippines and it aws observed that WSR systems used less water than transplanted rice for both land preparation and crop irrigation and the total water use reduced from 2,195 to 1700 mm. Less water used during land preparation is attributed mainly to the shorter time over which WSR farmers complete land preparation activities compared with transplanted rice farmers. The yield in WSR varied from 6.9 to 6.3 t /ha and water productivity increased from 0.3 to 0.4 (kg rice /m^3 water) by adopting WSR[9].

Real water saving can be seen by considering the different components of Evapotranspiration (ET). Rice yield per unit ET can be as high as 1.6 kg /m, which is comparable to that of other cereal crops. But when other water use components are taken into account, the field level water productivity of rice is reduced markedly. Water productivity with respect to ET varied from 1.39 to 1.61, water productivity with respect to ET + S & P (Seepage and percolation) from 0.48 to 0.68 and water productivity with respect to ET + S & P + LpR (Land preparation requirement) from 0.29 to 0.39 by adopting wet-seeded rice as compared to transplanted rice[9].

Table 3: Interaction effect of establishment methods v/s date of sowing on the grain yield (t /ha) of puddled irrigated Rice (mean of 2 seasons)

Treatment	Sowing dates		
	1 June	10 June	20 June
Establishment methods			
Direct sowing	4.99 (118)*	5.13 (119)	4.36 (122)
Transplanting 25 days after sowing	4.79 (127)	4.64 (129)	3.38 (133)
CD (P=0.05) (Interaction)	0.47		

*Days taken to mature

Source: [37].

Table 4: Seed rate, irrigation and methods of weed control influence on grain yield of direct seeded basmati rice

Seed rate (kg /ha)	Grain yield (t /ha)			
	Chemical weed control		Integrated weed control	
	Irrigation interval			
	2 days	3 days	2 days	3 days
50	2.40	2.26	2.75	2.33
100	2.24	2.20	2.43	2.31
150	2.11	2.02	2.40	2.20
Transplanted	2.29			
CD (P=0.05)	0.49			

Source: [36]

Compared direct seeding and transplanting methods on loamy sand soil at Ludhiana[37] and found that water productivity varied from 0.36 to 0.46 i.e. 25 % by adopting DSR with about 18 % less irrigation water consumption and with comparable yield as compared to transplanted rice. Studied yield, water input, and water productivity in transplanted, and wet-seeded rice, Talavera in dry season[98]. The different treatments were continuous standing water (2-5cm depth), standing water until panicle initiation, saturated soil thereafter, continuous saturated soil, and application of irrigation water (up to 5-7 cm depth) one day after standing water had disappeared. It was observed that differences in yield between DSR and transplanted rice became larger with reduced water input. The water productivity values for each of the treatment were higher in wet-seeded rice as compared to transplanted rice because of reduced water input in wet-seeding as compared to transplanting of rice.

The extent of water saving also depends upon irrigation scheduling. An experiment was conducted with two crop establishment methods (dry seeding and puddled transplanting) and four irrigation schedules[105]. The irrigation regimes were soil water tension (Soil Water Tension (SWT)-based irrigation scheduling when SWT at 20 cm increased to 20, 40, or 70 kPa (generically referred to as alternate wetting and drying treatments), plus a daily irrigated treatment. The daily irrigated PTR reflects current farmers' practice (continuous flooding), while PTR-20 kPa is similar to the current recommended practice of irrigating 2 days after the floodwater has dissipated.

The interaction effect between establishment method and irrigation schedule on grain yield was significant. Grain yield of PTR and DSR with daily and 20-kPa irrigation was similar and significantly higher than the yield of all other treatments. Grain yield was significantly higher in PTR irrigated at 40 and 70 kPa than in DSR-40 and 70 kPa, respectively. The higher yields of DSR and PTR with daily and 20-kPa irrigation were largely due to higher panicle density and more florets per panicle, and to a lesser degree to higher grain weight . The lower yields of DSR than PTR at 40 and 70 kPa were mainly due to lower panicle density, and to smaller degree to fewer florets per panicle, and lower grain weight.

An irrigation threshold of 20 kPa was the optimum in terms of maximizing grain yield and water productivity with respect to irrigation (WPI) of both PTR and DSR. Irrigation water productivity of DSR-20 kPa was much higher than that of PTR-20 kPa due to a 30 to 50% reduction in irrigation input, while grain yield was maintained. Water productivity with respect to ET was similar for both DSR-20 kPa and PTR-20 kPa as a result of similar yield and ET. Rice established with dry seeding was more sensitive to increasing the irrigation threshold beyond 20 kPa, resulting in lower grain yield and WPI, than for PTR at the same thresholds (40 and 70 kPa).

Although, direct seeding is itself a resource conservation technology and its effects can be further enhanced by adopting laser levelling . In case of transplanted rice, yield increased from 4.98 to 5.41 t /ha and from 5.10 to 5.25 t /ha in DSR by adopting laser levelling.The water productivity increased from 0.331 to 0.394 kg /m^3 in case of transplanting and from 0.409 to 0.468 kg m^3 by adopting laser levelling[77]. Thus, laser levelling is a pre-requisite in the improvement of water and crop management.

Labour use

Compared with CT-PTR, DSR is a labor-saving technology. Large variations in total labor requirement for various field operations for diverse practices were reported , which may largely be due to differences in the level of mechanization used. The total labour used was 37 % higher in conventionally planted rice as compared to DSR, which was mainly because of transplanting operation. In addition to labor savings, the demand for labor is spread out over a longer period in DSR than in transplanted rice. Conventional practice (CT-PTR) requires much labor in the critical operation of transplanting, which often results in a shortage of labor. The spread-out labor requirement helps in making full use of family labor, and having less dependence on hired labor[96].

Owing to the method of crop sowing and land preparation, it was observed that the labor requirement in DSR is lower with savings of 13-29% compared with CT-PTR (Table 5). The variation reported by different studies in labor savings primarily depends on labor used in weed control. Labor use is higher (12-200%) for controlling weeds in DSR than in CT-PTR. If weeds are controlled effectively with herbicides, the labor savings can be substantial. Direct seeding (both wet and dry) avoids nursery raising, seedling uprooting, and transplanting, and thus reduces the labor requirement. Dry-DSR also avoids puddling operations, and thus further saves labor use. Since land preparation is mostly mechanized, there is more savings in machine labor than in human labor in this operation. Short to medium term on-station studies reported 34–46 % savings in machine labor requirement in ZT-dry-DSR compared with CT-PTR[11, 84].

Emission of greenhouse gas (GHG)

Agriculture contributes in the emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) – these three GHGs contribute to global warming. Agriculture's share in the total emissions of N_2O, CH_4, and CO_2 are 60, 39, and 1, respectively [65], and rice-based cropping systems playing a major role. Rice production systems impact global warming potential (GWP) primarily through effects on methane but N_2O and CO_2 effects can also be important in some systems. The GWP of CH_4 and N_2O is 25 and 298 times higher than that of CO_2[43]. GHG emissions, especially CO_2 and CH_4 from rice fields, are large and very sensitive to management practices. Therefore, rice is an important target for mitigating GHG emissions[103]. Flooded rice culture with puddling and transplanting is considered one of the major sources of CH_4 emissions because of prolonged flooding resulting in lack of oxygen (anaerobic) soil conditions. It accounts for 10-20% (50–100 Tg year^{-1}) of total global annual CH_4 emissions[82]. Studies comparing CH_4 emissions from different tillage, and establishment methods in rice revealed that CH_4 emissions were higher in CT-PTR as compared to dry-DSR .The reduction in CH_4 emissions ranged from 30 to 58% in dry-DSR compared with CT-PTR[92,73].

When DSR was combined with mid-season drainage or irriregular interval irrigation (intermittent), the reduction in CH_4 emissions increased further compared with flooded transplanted rice. In wet-DSR, the reduction in CH_4 increased from 16-22% (under continuous flooding) to 82-92% (under mid-season drainage / intermittent irrigation) compared with continuously flooded CT-PTR [19]. Mid-season drainage in wet- or dry-DSR further enhanced CH_4 mitigation effects[103].

CH_4 emissions even in CT-PTR vary considerably in different studies, which might be due to the individual or combined effects of different soil characteristics, climatic conditions, and management such as soil pH, soil texture, redox potential, soil salinity, temperature, rainfall, and water management[4]. Aerobic conditions, especially during the early growth stages in dry-DSR and until seedling establishment in wet-DSR are responsible for low CH_4 emissions. Anaerobic conditions are a pre-requisite for the activities of methanogenic bacteria and CH_4 production. Methane emission starts at redox potential of soil below-150 mV and is further encouraged at less than-200 mV[46].

Economics

A major reason for farmers' interest in DSR is the rising cost of cultivation, and decreasing profits with conventional practice (CT-PTR). Growers likely prefer a technology that gives higher profit despite similar or slightly lower yield. The largest reductions in cost occurred in practices in which reduced or ZT was combined with dry-DSR. The observed cost

Table 5: Labour use (person-days /ha) in direct-seeded and transplanted rice

Location	Tillage & crop establishment methods	Total labour use (person-days /ha)	% labour saving	Reference
Uttar Pradesh	CT-PTR	66	0	[11]
	Bed-dry-DSR	47	29	
	ZT-dry-DSR	47	28	
Haryana	CT-PTR	64	0	[84]
	CT-wet-DSR (drum)	67	0	
	ZT-dry-DSR	56	13	

reductions were largely due to either reduced labor cost or tillage cost or both under DSR systems. In regions where wages are high (e.g., Haryana and Punjab states of India), the labor cost savings in rice establishment can reach US $ 50 /ha[53].

The effect of planting systems on grain yield, straw yield, cost of cultivation, net income and returns per rupee invested in rice grown on sandy clay loam soil was studied in Bangalore[87]. They observed direct seeding using drum seeder produced significantly higher net income Rs 34,953 per ha and returns per rupee investment (Rs 3.12) compared to net income Rs 30420 per ha and returns per rupee investment (Rs 2.66) recorded in transplanted system.

A field experiment was conducted in Paiyur to compare and assess the practical feasibility of different stand-establishment techniques in lowland irrigated rice[17]. Four stand-establishment techniques, viz. transplanting, throwing of seedlings, direct seeding by manual broadcasting and wet seeding by drum seeder were compared. Both the direct seeding practices registered the maximum net income of Rs 19,039 and Rs 18,587 /ha with B: C of 2.33 and 2.29 in manual broadcasting and drum seeder, respectively.

Effect on succeeding crops

Direct seeding helps to improve the soil structure which otherwise gets destroyed by continous puddling and thus provides congenial environment for succeeding crops.

In clay loam soil, a field experiment was conducted in Chhattisgarh[72] to access the crop establishment methods and irrigation regimes in rice followed by wheat crop (Table 6). Method of crop establishment followed for rice had a significant effect on wheat yield. The wheat yield was significantly low in the plots where rice was grown in puddled conditions compared to unpuddled conditions. Though the well puddled conditions provide congenial situation for rice, it also creates hard pan below the surface restricting the root growth and proliferation in deeper layers of winter crops. The effect of rice crop establishment methods of rice to improve the productivity and profitability of rice-based cropping systems was studied[33]. They observed that the system productivity of DSR-wheat, DSR-chickpea and DSR-mustard were higher (14.96 t, 14.48 t and13.48 t /ha , respectively) compared with the PTR based cropping system productivity (13.53 t, 12.12 t &11.81 t /ha , respectively).

Actual advantages from DSR

Direct-seeding of rice has the potential to provide several benefits to farmers and the environment over conventional practices of puddling and transplanting. The various benefits are enemurated below:

i. Saves labour (1-2 v/s 25-30 for PTR).
ii. Sowing can be done in stipulated time frame because of easier and faster planting.
iii. Early crop maturity by 7-10 days which allows timely planting of subsequent crops.
iv. More efficient water use and higher water stress tolerance.

Table 6: Effects of crop establishment methods on yield and yield attributes of rice and on following wheat

Treatments	Rice			Wheat		
	Effective tillers /m^2	Filled grains/ panicle	Grain yield (t /ha)	Effective tillers /m	Grains /ear	Grain yield (t /ha)
Puddling and transplanting	277	114	5.32	73	36.2	2.98
Line sowing of sprouted seeds (Puddled)	276	112	5.14	76	35.9	3.03
Line sowing of Sprouted Seeds (Unpuddled)	269	105	4.76	79	36.4	3.23
CD (P=0.05)	6.0	7.0	0.31	4.0	NS	0.23

v. More profitability especially under assured irrigation facilities.
vi. Better soil physical conditions.
vii. Less methane emission: DDS (dry direct seeding) < WDS (wet direct seeding) < PTR (Transplanted rice).

Constraints associated with DSR
Weeds

Weeds are the most important constraint to the succeess of DSR in general and to Dry-DSR in particular[93, 80]. The weeds pose to be more problematic in DSR than in puddled transplanting because (1) The emerging weeds are more competitive as compared to the simultaneously emerging DSR seedlings and (2) lack of water layer in Wet- and Dry-DSR make these crops more prone to initial weed infestation which lacks otherwise in case of transplanting[52, 80]. The research has shown that, in the absence of effective weed control options, yield losses are greater in DSR than in transplanted rice . The reported range of such yield losses in DSR in India is 20-85 %[80].

Shift and Changes in weed flora

Composition of the weed flora can change drastically with a shift from CT-PTR to alternative tillage and rice establishment methods[94]. As a result of shifting from flooded to direct seeding system, there is variation in water, tillage and weed management practices which results in changes in weed composition and diversity. Tomita *et al.* (2003) observed more species-rich vegetation and diverse weed flora in Dry-DSR than in CT-PTR. A total of 46 species were present in transplanted rice in 1989, and, after 3 years (six seasons) of Wet-DSR, 21 new weed species were added to the weed flora[62]. In a study conducted in Modipuram, India, the number of species of grasses, broadleaves and sedges were 6, 4, and 4, respectively, in CT-PTR, whereas, in Dry-DSR, it increased to 15 grass, 19 broadleaf species, and number of species of sedges remained unaffected[94]. This clearly shows that some new grass and broadleaf species that were not adapted to CT-PTR appeared in Dry-DSR. Higher numbers and more diverse flora in Dry-DSR could result in lower efficacy of weed management strategies, including herbicides. In addition, adopting DSR may result in weed flora shifts toward more difficult to control and competitive grasses and sedges. For example, in Malaysia, at the time of the introduction of direct seeding (Wet-DSR) in the 1970s, easy-to-control broadleaf weeds were dominant but, by the 1990s, grass species such as *Echinochloa crusgalli, Leptochloa chinensis,* and *Ischaemum rugosum* became dominant[5]. Similar shifts in weed flora were reported in Malaysia[41] when rice crops shifted from CT-PTR to Dry- and Wet-DSR (Table 7).

Table 7: Weed species shift and weed population dynamics due to changes in the method of rice establishment

Weed flora	Method of establishment and year		
	Transplanted (1979)	Dry seeded (1987)	Wet seeded (1989)
No. of species	21	50	57
No. of genera	18	38	44
No. of families	13	22	28
Major weed species (ranked by density)	*Monocharia vaginalis* *Ludwigia hyssopifolia* *Fimbristylis miliacea* *Cyperus difformis* *Limnocharis flava*	*Echinochloa crusgalli* *Echinochloa colona* *Leptochloa chinensis* *Scirpus grossus* *Fimbristylis miliacea*	*Echinochloa crusgalli* *Leptochloa chinensis* *Fimbristylis miliacea* *Marsilea crenata* *Monocharia vaginalis*

Source: [41]

In a long-term and more detailed field study conducted in Malaysia, weedy rice and *L. chinensis* were absent in Wet-DSR plots at the start of the experiment in 1989. However, *L. chinensis* appeared after only 2 years (in 1991) and weedy rice after 4 years (in 1993) of experimentation. By 2001, weedy rice, *Echinochloa crusgalli, L. chinensis, and Fimbristylis miliacea* became the dominant species[62]. In Vietnam also, shifts toward more difficult to control grass weed species (*E. crusgalli*, *L. chinensis*, and weedy rice) were observed with the introduction of DSR[22]. Dicotyledonous weeds are dominant in transplanted rice, but annual grasses such as *E. crusgalli and L. chinensis* and sedges such as *F. miliacea* in DSR fields in Vietnam[101]. Similar shifts have also been reported in India. It has been observed that *E. crusgalli, Commelina diffusa*, *Cyperus rotundus*, *Cyperus iria*, and *L. chinensis* were dominant in control Dry-DSR plots in comparison with *C. iria*, *Echinochloa colona*, and *Caesulia axillaris* in CT-PTR plots after four seasons of rice cropping [95]. Direct seeding also favors sedges (Rushlike or grasslike) such as *Cyperus difformis, C. iria, C. rotundus*, and *F. miliacea*[62]. Therefore, it is important that a systematic weed monitoring program be put in place along with the introduction of DSR. This would make it possible to develop effective integrated weed management (IWM) strategies,including identification of new herbicides that are effective against a wide spectrum of weeds.

Development of herbicide resistance

The practice of direct seeding on large scale increased herbicide use for weed control in rice, which slowly resulted in the appearance of resistance in weeds against certain herbicides. For example, the first case of herbicide resistance was reported in *F. miliacea* against 2,4-D in 1989 in Malaysia. But, later on, the numbers of resistant weed biotypes to different herbicides increased to 10. In Thailand, Korea, and the Philippines, the number of herbicide-resistance cases in weeds increased from zero before DSR introduction to 5, 10, and 3, respectively, after its introduction[54].

Emergence of weedy rice

Weedy rice/red rice (*O. Sativa, F. spontanea*), has emerged as a serious concern to rice production in areas where direct seeding especially Dry-DSR widely replaces CT-PTR. Weeds in rice are highly efficient and causes severe rice yield losses ranging from 15 to 100 %[54]. Milling quality is also impaired if weedy rice gets mixed with rice seeds during harvesting[67]. Weedy rice is difficult to control because of its genetic, morphological, and phenological similarities with rice. Selective control of weedy rice was never achieved at a satisfactory level with herbicides[64]. In Malaysia, proper land preparation along with the stale seedbed technique using nonselective herbicides before planting rice has been recommended to reduce the density of weedy rice[47]. Recommends an integrated approach that combines preventive, cultural, and chemical methods[29]. The important factors for control and to avoid further infestation are to use clean and certified seeds (Rao *et al*., 2007). Herbicide resistant rice technologies offer opportunities for selective control of weedy rice but the risk of gene flow from herbicide resistant rice to weedy rice poses a constraint for the long-term utility of this technology[52]. There is need to develop effective management strategies for keeping weedy rice under check.

Increase in soil-borne pathogens such as nematodes

Root-knot nematodes pose a severe constraint when shift from PTR to DSR takes place. Root-knot nematode, *Meloidogyne graminicola* was first reported in 1963 from the Louisiana State University, Baton Rouge, USA.

In a study in Philippines, RKNs were found to be most damaging pathogen for aerobic rice Apo[77]. As shown in table 8, rice yield in untreated plots was 0.2-0.3 t /ha in 2006 and nil in 2007. However, in plots treated with nematicide dazomet yield of 2.2 t /ha was obtained in 2006 and 2.4 t /ha in 2007. In the first year, degree of galling in rice roots was only 0.4 in the nematicide-treated plots,whereas it was 3.4-4.4 in untreated plots. In 2007, galling increased even in nematicide-treated plots to 2.4, whereas it was 4.8-4.9 in untreated plots (Table 8).

Higher emissions of nitrous oxide

Although direct seeding can help in reducing CH_4 emissions, but aerobic soil conditions can also increase N_2O emissions. Nitrous oxide production increases at redox potentials above 250 mV[42]. In a study conducted in India[54], N_2O emissions from CT-PTR were compared with different Dry-DSR methods (CT-dry-DSR, Bed-dry-DSR, ZT-dry-DSR),it was found that N_2O emissions were 0.31–0.39 kg N /ha in CT-PTR, which increased to 0.90–1.1 kg N /ha in CT-dry-DSR and Bed-dry-DSR and 1.3– 2.2 kg N / ha in ZT-dry-DSR. Higher emissions of N_2O under ZT-dry-DSR than in CT-PTR was also observed[44] in western Japan.

So, certain strategies need to be adopted to reduce N_2O emissions from Dry-DSR for minimizing adverse impacts on the environment. Developing water management practices in such a way that soil redox potential remains in between -100 to -200 mV, this can minimize emissions of both CH_4 and N_2O. This range is high enough to prevent CH_4 production and low enough to encourage N_2O reduction to N_2 as the critical soil redox potential identified for N_2O production is -250 mV[42]. Despite of the relatively higher emissions of N_2O in Dry-DSR, global warming potential (GWP) of Dry- DSR will be lower than for flooded CT-PTR because of substantially higher emissions of CH_4 in CT-PTR. An overall effect of direct-seeding methods on GWP depends on total amount of all three major greenhouse gases (GHGs) i.e. carbon dioxide, methane and nitrous oxide. The measures taken to reduce one source of GHG emissions often lead to increase in other GHG emissions, and this trade-off between CH_4 and N_2O generally is a major problem in devising an effective GHG mitigation strategy for rice[103].

Nutrient disorders, especially N and micronutrients

Nutrient dynamics altogether varies in both DSR and PTR systems mainly because of the difference in land preparation and water management techniques. In case of DSR, soil remains aerobic beacause of dry land preparation as compared to PTR where soil is kept flooded and is puddled. Puddling has positive impact on weed control[85] and nutrient availability[102].In submerged conditions, less oxygen in the rhizosphere prevents oxidation of NH^{4+} and thus reduce leaching[50], increase availability of P [63, 104, 91] as well as of Fe[68, 97].

Deficiencies of micronutrients are of major concern in DSR. A shift from PTR to DSR affect Zn availability to rice[34] and it reduces because of reduced release of Zn from highly insoluble fractions in aerobic rice fields[49]. Zn deficiency is caused by high pH, high carbonate content[58] and more bicarbonates in calcareous soils[31] which immobolize Zn because of inhibition effect[26]. Availability of P and Zn increases when pH is below neutral in the rhizosphere[49], because of their increased solubility[86]. Zn uptake by DSR is also affected by source as well as time of Zn application[38].

Availability of Fe is often particularly high in anaerobic soils because of low redox potential. In aerobic soils, however, Fe may become limiting, especially when the soil pH is high. Moreover, nutrient uptake and supply to plants may be reduced because of lower delivery rates to roots through

Table 8: Grain yield and root – knot nematode (RKN) galling at flowering in the roots of aerobic rice Apo at Tarlac, Philippines

Treatment	Grain (t /ha)		RKN	
	2006	2007	2006	2007
DSR	0.2b	0.0b	3.7a	4.8a
Biocide + DSR	2.2a	2.4a	0.3b	2.4b
Transplanted rice	0.3b	0.0b	4.4a	4.9a

RKN-degree of galling on a scale of 1-5.
Biocide – Dazomet @ 50g a.i. m -2, 6-7 weeks before seeding.
Source: [77]

Table 9: DTPA-extractable iron (ppm) in the soil at 0-15 and 15-30 cm depth at maximum tillering stage

Establishment method	Depth (cm)	
	0-15cm	15-30 cm
Transplanted rice	5.07	5.81
Water seeded rice	5.03	5.13
Dry seeded rice	2.26	2.28
Dry seeding on raised beds	2.55	2.61

Critical limit: 4.5 ppm
Source: [91]

mass flow and diffusion as both of these processes are influenced by the reduced soil water content. Thus,unsaturated soil conditions in DSR fields can lead to iron deficiency and plants show chlorosis. Prolonged iron deficiency may result in severe yield losses in DSR, hence care should be taken to manage iron deficiency.In the dry-seeded aerobic treatments, the iron content was about half of that in the submerged PTR and WSR treatments (Table 9). The values of 2.1-2.6 ppm in the aerobic treatment were below the critical limit of 4.5 ppm[91].Therefore, appropriate nutrient management strategies based on nutrient dynamic studies in DSR need to be developed.

Stagnant yield

Yield decline in DSR has been reported [100,51], which may be due to various reasons viz., soil sickness[99], plant autotoxicity[23, 45, 66, 27] presence of *G. graminis* var. graminis in dry-seeded rice fields 75, and continously growing DSR for more than two years[28].

Lodging

Lodging is the permanent vertical displacement of the stem of a free-standing crop plant[8]. DSR is more prone to lodging as compared to PTR[90]. Lodging makes the harvesting of the crop difficult and also reduces yield and impairs the quality of rice both in terms of appearance and taste[59, 90]. Rice cultivars having lodging resistant characteristics viz., intermediate plant heights, large stem diameters, thick stem walls and high lignin content[56] should be preferred. Moreover, thicker band of sclerenchyma at the periphery of the stem[79] and more vascular bundles[21] makes the cultivars more resistant to lodging.

Diseases and insect pests

DSR is susceptible to various diseases and rice blast is one of the most common[12]. and damage due to rice blast increases under water stress conditions[13]; since the water level affects several processes such as liberation and germination of spores and infection in rice causing blast[48]. The crop microclimate especially dew deposition is affected by water management which makes the environment congenial for host susceptibility[89, 83]. The changes in the crop physiology as influenced by water management also triggers host susceptibility[13]. In aerobic rice, blast resistance is the foremost important trait for breeding programs in Brazil[16].

In DSR, the other disease and insect problems reported are sheath blight and dirty panicle[74], brown spot disease and plant hoppers[89] and soil borne pathogenic fungus *Gaeumannomyces graminis var. graminis* in dry-seeded rice in Brazil without additional irrigation[76].

Others

i. Rice seeds are exposed to birds and rats.
ii. Sudden rain immediately after seeding can adversely affect crop establishment.
iii. Uneven crop stand also results in failure of obtaining potential yield of DSR.

Possible solutions

- Integrated weed management
- Systematic weed monitoring programme
- Biocide use for nematode control
- Prefer slow release N fertilizers, nitrification inhibitors & split application of N.
- Soil application of Zn and foliar application of Fe
- Hill seeding, lodging resistant cultivars, optimum N dose, seeding rates, depth & method can help to overcome lodging.
- Seed priming tools for improving stand establishment
- Integrated management as well as bio-technological and genetic approaches may help resolve insect, pest and disease issues.

Hill seeding in DSR to overcome lodging

Comparing different seeding methods of direct seeding cultivation, lodging resistance is considered to be highest in hill-seeded rice (Table 10). Hill-seeded rice showed remarkable higher pushing resistance than broadcast-seeded rice across a range of seedling density and seeding depth after heading, where the plant length was longer in hill-seeded rice. High lodging resistance of the hill seeded rice was from the large number of panicles per hill, because the lodging resistance varied depending on the number of panicles in a hill. The area under hill seeder acconts for about 25% of the total submerged direct-seeded area[106].

Herbicides under Punjab conditions

Based on the field experiments conducted at research farm of PAU, Ludhiana, it was observed that pre-emergence spray of pendimethalin 0.75 kg /ha followed by post-emergence spray of bispyribac 0.025 kg /ha provides excellent control of weeds resulting DSR grain yield of 5.3 t /ha as compared to either pre-emergence spray of pendimethalin 0.75 kg /ha (2.0 t /ha) or post-emergence spray of bispyribac 0.025 kg /ha alone (2.2 t /ha)[1].

Seed Priming

Seed priming technique helps to improve emergence as well as stand establishment under variable field conditions. Seed priming techniques were explored for improving germination and crop performance of dry direct-seeded rice[57]. Seed-priming treatments used during the investigation included untreated control, hydro-priming, water hardening, and osmo-hardening with KCl. Priming reduced mean germination time and improved germination index, seedling vigor index, and germination energy. Hydro-priming was the best treatment, followed by water hardening, in improving seedling growth, leaf area index, panicles m^{-2}, and grain yield of dry direct-seeded rice.

Model Package for DSR

A model package has been proposed based on the series of on-station and on farm field experiments from 2006-2010 under a research project "Zero tillage rice establishment and crop weed dynamics in rice and wheat cropping system in India and Australia" at Punjab Agricultural University[10].

Laser leveling and field preparation

Precise leveling is pre-requisite for direct seeding. Preferably laser leveling should be done at least a month before sowing. After laser leveling, the field should be irrigated to identify uneven areas in the field which can be taken care of through fine leveling again. This irrigation also stimulates weed and previous rice crop seed germination, which can be killed before seeding rice. To prepare a fine seed bed, plough the field twice with disc harrow followed by two cultivations with cultivator and one planking.

Soil type

Direct seeding should be done on medium to heavy textured soils as direct seeded crop in light soils suffers from iron deficiency which causes remarkable reductions in yield.

Sowing time

Sowing time varies with location to location. First fortnight of June is the optimum time for direct seeding of coarse rice in north-west India. For direct seeded basmati rice, optimum sowing time is second fortnight of June. As a general rule, seeding time of DSR should be as close as possible to the time of nursery sowing for the PTR.

Seed drill

Among various seed drills used for direct seeding (viz., conventional seed cum fertilizer drill, zero till drill, Inverted T-tyne zero-till seed - cum-fertilizer drill,Vertical plate metering mechanism and inclined plate metering mechanism), machines with inclined plate metering mechanism are most suitable for DSR.This types of machines help in

Table 10: Effects of seeding method on characteristics of plants and lodging resistance

Seeding method	Culm length (cm)	Number of panicles /hill	Pushing resistance (g /culm)	Lodging index	Lodging degree (0-4)
Broadcast-seeding	79.4	2.7	39.5	1.44	1.87
Hill-seeding	84.5	25	71.9	0.75	0.67

Plant density: 160 plants /m^2
Source: [106]

maintaining row to row and seed to seed spacing with little breakage.The sowing depth for dry DSR should be 2-3 cm and 3-5 cm for DSR after pre-sowing irrigation.The row to row spacing should be 20 cm.

Seed rate and treatment

Seed rate @ 20-30 kg /ha is adequate, when using planters with precise seed metering systems. Treat the rice seed with fungicides like streptocycline 1 g+bavistin 10 g/10 kg seed to reduce seed and soil borne diseases like bacterial leaf blight,sheath blight,brown leaf spot and other diseases.

Nutrition

The recommended doses of P, K and Zinc for DSR and PTR are same and apply these at the time of sowing.Apply K on soil test basis. Apply N @ 150 kg /ha in 4 splits 2, 4, 7 and 10 weeks after seeding.In case of basmati rice,apply 25% higher N dose in direct seeding as compared to transplanted crop.

Varieties

Short and medium duration rice varieties should be preferred. PR 115 variety of coarse rice and Pusa Basmati1121, Punjab Mehak 1, CSR 30, Pusa basmati 1 and Taraori basmati varieties are most suitable for direct seeding of basmati rice.

Irrigation management

In heavy textured soils, DSR crop is commonly established by farmers with pre-sowing irrigation.First post-sowing irrigation can be delayed from 7-15 days with subsequent irrigations at an interval of 5-10 days.Water stress must be avoided during critical stages of seedling emergence,active tillering, panicle initiation and flowering.

Weed Management

Effective weed control is pivotal for DSR. Cultural methods of weed control like stale seed bed technique, use of surface mulch, cover crops (viz., *Sesbania rostrata*, *Phaseolus radiatus* and *Vigna unguiculata*) and brown manuring can help to reduce weed pressure.Pre-emergence treatment with pendimethalin (0.75 kg /ha) followed by post emergence application (15-25 days after sowing) of bispyribac (0.025 kg /ha) for controlling grasses,broadleaf as well as sedges, azimsulfuron (0.020 kg /ha) for controlling broadleaf and sedges including *Cyperus rotundus* and Fenoxaprop+ safener (0.067-0.083 kg /ha) for effectively controlling grasses except *Echinochloa* sp.

CONCLUSION

- Comparative yields of DSR (2.2-8.7 t /ha) can be obtained by adopting proper management practices.
- DSR sowing is more cost effective technology as B: C varies from 2.29-3.12 as compared to transplanting (1.93-2.66).
- Water productivity is high in DSR and exceeds corresponding values in transplanting by >25%.
- Labour saving in DSR ranges from 13-37%.
- Pre-emergence spray of pendimethalin 0.75 kg /ha followed by post-emergence spray of bispyribac 0.025 kg /ha provides excellent control of weeds.
- Seed priming is the promising approach to overcome poor crop establishment.
- DSR is technically and economically feasible, eco-friendly alternative to conventional puddled transplanted rice.

Future outlook

- Development of new rice varieties for direct seeding along with proper management practices can help in adoption of DSR.
- The change in the weed flora associated with switching over from PTR to DSR can be tackled by systematic weed monitoring program in association with integrated weed management strategies on sustainable basis.
- Proper management of microelements is also desirable since availability of microelements is reduced by direct seeding of rice.
- Selection of proper soil type along with precised levelling can help to enhance WUE and productivity. Further, the selection of crop varieties with characters like early crop vigour and short statured cultivars with short duration can further increase WUE.
- In direct seeding culture, WUE and productivity may improve if appropriate soil types from

levelled land are selected. The various features of the crop like early crop vigour, short stature and short duration also helps in increasing WUE.

- Seed priming technology can help to get rid of the problem of poor establishment of crop and can be further improved.
- Strategies to reduce NO_2 emissions can be worked out.
- Biotechnology can help to resolve the minor issues like lodging, nematode infestation, diseases, etc.

Despite of the numerous controversies, comparable grain yields may be obtained from DSR if properly managed as compared to PTR. Thus, in the present scenario of global scarcity of water and increasing labour wages, when the future of rice production is at stake, DSR is the most viable option for getting sustainable yields without any overexploitation of the available natural resources.

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