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Direct-seeded Rice: Potential Benefits, Constraints and Prospective

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Direct seeded rice (DSR) production has become a competitive substitute for traditional transplanting methods, offering several benefits such as decreased greenhouse gas emissions, labor and water savings, and improved resource efficiency. An extensive summary of the current status of DSR cultivation is given in this abstract, focusing on its agronomic, economic, and environmental aspects. This study covers the main concepts and techniques of DSR cultivation, including weed control, seed selection, land preparation, sowing techniques, and nutrient application. It examines current scientific findings and technological developments aimed at enhancing DSR systems, such as the development of high-yielding, stress-tolerant rice cultivars that can be seeded directly, with precision tools, and with integrated weed management practices. The environmental impacts of DSR cultivation are explored, highlighting its contributions to water conservation, soil health improvement, and greenhouse gas emission reduction. These benefits are

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examined alongside the agronomic and financial advantages, providing a holistic view of DSR's potential. However, the review also identifies several challenges and barriers to the widespread adoption of DSR, including technological constraints, gaps in farmer knowledge and expertise, and socioeconomic issues. Addressing these challenges requires significant research, extension services, policy support, and farmer capacity-building programs. The valuable insights into the potential of direct seeded rice cultivation as a sustainable, efficient, and environmentally friendly method of rice production. The implications for food security, resource conservation, and rural livelihoods are profound, suggesting that DSR could play crucial role in future agricultural practices.

Keywords: DSR, environmental sustainability; economic; food security.

1. INTRODUCTION

Over half of the world's population relies heavily on rice as a food source. Asia grows and consumes almost 90% of the world's rice. The phrase "rice is life" is most fitting for India, as this crop is essential to the nation's food security and provides the primary source of income for millions of rural households [1]. It provides 43% of the calories needed by over two thirds of the Indian population, making it the main source of food after wheat. Kaur and Singh, [2]. Sustainable agricultural practices include the successful management of resource for agriculture to satisfy changing human need while maintaining the quality of the environment and conserving natural resources. The rapid climatic events that cause erratic rainfall and abiotic stresses, the impending water and energy crisis, low nitrogen use efficiency, increasing micronutrient deficiencies, rising labor costs and decreased labor availability, increased methane emissions, yield stagnation, and the detrimental effects of rice crops on post-rice crops are all factors endangering the long-term sustainability of this flooded rice system [3]. Growing labor costs and the fact that rice requires a lot of water to cultivate lead to a search for substitute crop establishment techniques that can enhance water productivity. There is no other practical way to lessen the unproductive water flows than to use direct seeded rice (DSR). Since the 1950s, it has been acknowledged as the primary technique for establishing rice in developing countries. Kaur and Singh [2] In order to get out of this predicament, strategies for lowering water requirements and raising rice productivity must be developed [4]. Some of the main issues that call for the development of alternative establishment methods to sustain rice productivity and natural resources are the declining water table, labor shortages during peak periods, and declining soil health. The growing popularity of direct seeded rice (DSR) as a low-input alternative to traditional puddled transplanted rice is due to its practicality. It provides a number of benefits, including labor savings, reduced water requirements, enhanced climate risk adaptation, reduced drudgery, early crop maturity, low production costs, improved soil physical conditions for subsequent crops, reduced methane emanation, better options for being the best fit in various cropping systems, and an exciting opportunity to enhance water and environmental sustainability. Currently, Indian farmers are gradually implementing Dry Direct Seeded Rice, or DDSR, broadcasting dry seeds into well-pulverized soil either manually or with the use of tillage equipment [5]. In a study Tripathi et al*.* [6] concluded that when growing rice, farmers favored direct seeding because the TPR method required a lot of labor. DSR increases rice farming's economic returns while requiring less labor. Adopting various cultural practices, such as choosing appropriate cultivars, timing the sowing process, using the best seed rate, and managing weeds and water, can help produce comparable yields in DSR. Kaur and Singh [2]. Many farmers have been encouraged to switch from transplanted to DSR culture due to the development of short duration, early maturing cultivars, effective nutrient management techniques, and increased adoption of integrated weed management methods [7].

2. DIRECT SEEDED RICE AND ITS ESTABLISHMENT METHOD

The process of growing rice crop in the field by sowing of seeds in the field rather than by transplanting seedlings from the nursery is known as direct seeding of rice. Following the completion of germination and seedling establishment, the crop can be successively flooded and water regimes maintained, just like with transplanted rice. Alternatively, the crop may continue to be rainfed although the condition is the upper layers of soil vary between aerobic and non-aerobic. Bista [8].

Method of Establishing Direct Seeded Rice (DSR): There are three principles method of establishing direct seeded rice.

1. Dry seeding: Dry seeds are sown in dry and mostly aerobic soil. Several methodologies can be used to establish it, such as: a) Dispersing dry seeds on soil that isn't puddled after ZT or CT b) Dibbled method in a well-prepared field and c) Drilling of seeds in rows after CT, minimum tillage (MT), zero tillage (ZT) using a power tiller operated seeder [7].

2. Wet seeding: Pre-germinated seeds (radicle 1- 3 mm) are sown on or into puddled soil in wet-DSR. When pre germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic Wet-DSR. When pre germinated seeds are sown / drilled into puddled soil, the seed environment is mostly anaerobic and this is called as anaerobic Wet-DSR. Wet-DSR Seeds can be broadcasted or sown in-line under aerobic and anaerobic conditions using a drum seeder or an anaerobic seeder with a furrow opener and closer. Rainfed lowlands and irrigated areas with adequate drainage facilities make up a suitable ecology.

3. Waterseeding: In this method pregerminated seeds sown in standing water. Broad casting on standing water (5-10 cm) [7]. It is used in regions with red rice issues as well as irrigated areas with good land leveling. Farooq et al*.,* [9]

Comparison between DSR and TPR

2.1 Growth

Taller plant, more dry matter accumulation and increased number of tillers per meter square can be produced under direct seeded rice in comparision to transplanted rice [10]. The result was in agreement with Karthika et al*.,* [11] in a weed management experiment under direct seeded rice and reported higher number of panicle than transplanted rice. In contrary to this Akkas et al*.* (2006) and Bheru et al. (2016) observed and reported taller plants under transplanted rice (106.1 cm) compared to direct-seeded rice (98.5 cm). Similarly, they stated that transplanted rice compared to direct seeded rice is able to produce more dry matter dry.

2.2 Nutrient Uptake and Nutrient Use

Puddled transplanted rice condition reduced leaching losses of nutrients resulted increased uptake and utilization by crop plants. Chander and Pandey [12] and Sandhya et al*.,* [13] in an experiment on rice under PTR and DSR noticed significantly higher N, P and K uptake than direct seeded rice. PTR minimized weed problem also helps in more availability of nutrients to crop.

2.3 Weed Dynamics

Dominant weed species, rice-weed competition, and ultimately the weed control strategy are largely determined by variances in rice ecosystems and cultural practices. Saravanane et al*.,* [14]. The yield losses vary under rice establishment method. In general, more yield loss observed under direct seeded rice conditions in with respect to transplanted rice. Dass et al*.,* [15] observed thatWhen it comes to puddled transplanted rice, yield losses can reach 50–60% and 70–80% in DSR.

Crop establishment techniques also had an impact on weed management strategies and increased the effectiveness of weed control. Parameshwari et al*.,* [16] In their experiment, the highest weed control efficiency under transplanted and direct seeded rice was found to be 90.4 and 88.1 percent, respectively. Hassan et al*.,* [17] found that Compared to WSR, transplanted rice produced a higher grain yield by reducing both the number of weeds and dry matter with a higher weed control efficiency.

2.4 Crop Establishment Methods on Yield Attributes and Yield

Puddled transplanted rice condition reduced losses of nutrients increased availability to crop plants as well as minimized crop weed competition resulted enhance crop yield and yield attributes [18,19]. From an experiment they reported enhanced yield contributing traits as well as grain yield. The highest grain weight of 1000 was seen in rice that was directly sown, and then rice that was transplanted. Iqbal et al*.,* [19].

Grain yields in transplanted rice (4367 kg/ha), which were noticeably higher than those in direct seeded rice (2992 kg/ha). Prasad et al*.,* [18] While, Parameshwari et al*.* [16] observed no discernible variations in the quantity of grains across the various crop setup techniques test weight, panicle-1, and panicle length.

2.5 Water Saving

In the future, feeding a large population and providing for their water needs will be difficult. To achieve global food security, agricultural water resource consumption must be sustainable. Du et al. [20] There are three ways to deal with the food scarcity brought on by the water shortage.: (iboosting water availability by recycling wastewater, (ii) improving water productivity by increasing yields, optimizing water use, or doing both, and (iii) utilizing virtual water trade to import water in the form of food in order to address the regional water shortage (Fereres et al., 2011 The primary goals of all three strategies are to increase crop water use efficiency through integrated techniques, maximize the use of rainfall that is available, and make efficient use of the limited irrigation waterThis can be accomplished using a range of methods and tools, such as (i) upgrading and optimizing irrigation and drainage systems, (ii) building and lining field channels and waterways, (iii) land leveling and shaping, (iv) constructing field drains, (v) combined use of groundwater and surface water, (vi) appropriate cropping patterns to be implemented and regulated, (vii) rotating water distribution systems and enforcing them (viii) creating strategies for supplying inputs like funding, seeds, fertilizer, and pesticides, and (ix) enhancing the present extension, education, and demonstration initiatives in farmers' fields to reduce freshwater use and boost irrigation effectiveness.

Research observations as reported by researcher's In comparison to TPR, DSR had higher water productivity. With sesbania co-culture, DSR achieved the highest water savings (39.4%). Water productivity of rice Pusa 44 was 0.45 kg m when grown in DSR without crop residue while it was 0.43 kg m with sesbania co-culture. The maximum water saving was 32.3% in DSR with sesbania. Bhandari et al*.,* [24] reported that Water consumption can be reduced by up to 60% because TPR culture no longer requires seepage, percolation, puddling, or nursery raising. Similarly, Pathak et al*.,* [1] reported that Transplanted rice with continuous standing water has relatively high water inputs and low water productivity when compared to other rice cultivation techniques that use water during the crop growth period and increase water productivity by 25–48%. Unlike transplanting, which requires 450 mm of rainwater, rice can be established by DSR once 150 mm of rain or irrigation water has accumulated.

2.6 Labour and Cost Saving

Concerns about a labor shortage have emerged recently, which drives up the cost of transplanting and delays planting. Direct seeding reduces the need for labor for nursery growth and transplanting by avoiding the need to grow the seedling and transplanting. For nursery raising, uprooting, and transplanting seedlings, labor requirements are reduced by approximately 40%, and the cost of the work is minimal. Human labour use also reduced to 40-45% and tractor use to 50-60% in DSR compared to transplanted rice [1].

Zero-tilled-direct-seeded rice systems needed 34–60% less effort for mechanization than puddle-transplanted rice systems. Switching from PTR to wet-DSR saved 13–49% of labor [25]. Compared to transplanted rice, direct-seeded rice requires less paid labor and uses family labor because the labor demand is distributed over a longer time frame. On the other hand, according to researchers like [26] direct-seeded rice requires 12–200% more labor to suppress weeds than puddle- transplanted rice but reduces labor and energy footprints.

Table 1. Water productivity and efficiency of direct-seeded rice

S.No.	Season/Location	WUE or Water Productivity (WP) or % Water Saving	Reference
1	PAU, Ludhiana	Water productivity in DSR varied between 0.40 and 0.46, while irrigation water under transplanted rice ranged from 0.29 to 0.39 kg grain m^{-3}. The water productivity under DSR is 17.9–27.5% higher with respect to transplanted rice.	Gill et al. [21]
2	Punjab, India	DSR at 20 kPa increased water productivity without lowering productivity and decreased irrigation input by 30 to 50%.	Yadav et al. [22]
3	University of Agriculture, Faisalabad, Pakistan	In comparison to transplanted rice, which has a water productivity of 1.1 kg grain m^{-3} under sandy loam soil, DDSR has a water productivity of 1.4 kg grain m^{-3} and saves 8–12% of water.	Ishfaq et al. [23]

3. ECONOMICS

Farmers are becoming more interested in DSR due to the rising cost of rice cultivation and declining profits from conventional practice (CT-PTR). Growers probably go for a technology that yields a slightly lower yield but still yields a higher profit. The methods that combined reduced or ZT with dry-DSR resulted in the biggest cost savings. Under DSR systems, labor costs, tillage costs, or both, were reduced, which contributed significantly to the observed cost reductions. In comparison to the transplanted system, which yielded net income of Rs 30420 per ha and returns per rupee investment of Rs 2.66, direct seeding with a drum seeder produced significantly higher net income of Rs 34,953 per ha and returns per rupee investment (Rs 3.12) (Kaur and Singh [2] Younas et al*.* [27] Awan et al*.* [28] and Ali et al*.* [29].

3.1 Need for Direct Seeded Rice

Direct seeded rice (DSR) cultivation is imperative for agricultural sustainability [1,24] in various ways:

a) Prior to the green revolution in India, direct seeding rice was a common practice. Due to its potential to save labor and water, it is becoming popular again.
b) It is becoming more and more well-known as the most practical substitute technique that gets around all of the shortcomings of the transplanting method.
c) Puddling, transplanting, and maintaining standing water in rice fields—basic rice cultivation tasks—are omitted.
d) When transplanting shock is not present, DSR reaches maturity seven to ten days before transplanted rice.
e) About 40% of the labor needed for nursery raising, seedling uprooting, and transplanting is saved.
f) Up to 60% less water used since seepage, percolation, puddling, and nursery raising are eliminated [1].
g) The usual method for growing rice is to transplant seedlings into puddled soil. Rice benefits from puddling because it lowers water percolation losses, suppresses weeds, makes seedling establishment easier, and creates an anaerobic environment that improves nutrient availability.
h) But puddling repeatedly damages soil aggregates, lowers permeability in surface layers, and creates hard pans at shallow depths, all of which can have an adverse effect on the non-rice upland crop that follows in rotation.
i) In addition, rice production is less profitable because puddling and transplanting need a lot of labor and water, both of which can become scarce and costly. Due to all of these reasons, direct seeding of rice must replace puddled-transplanted rice production.

3.2 Constraints Associated with DSR

Kaur and Singh [2] and Farooq et al*.* [30] elaborate the constraints experienced during direct seeded rice cultivation.

a) When compared to the DSR seedlings that are also emerging at the same time, the emerging weeds are more competitive Kaur and Singh [2].
b) Wet- and Dry-DSR crops are more susceptible to early weed infestation due to the absence of a water layer, whereas transplanting eliminates this risk. Kaur and Singh [2].
c) The emergence of weedy rice: In regions where direct seeding, particularly Dry-DSR, is frequently used in place of CT-PTR, weedy rice, also known as red rice (O. Sativa, F. spontanea), has become a major concern for rice production. If weedy rice is harvested and mixed with rice seeds, the quality of the milling process is also affected. Due to its genetic, morphological, and phenological similarities with rice, weedy rice is challenging to control. Herbicides were never able to successfully control weedy rice on a selective basis. It has been advised to reduce the density of weedy rice by using nonselective herbicides in conjunction with the stale seedbed technique before planting rice. Kaur and Singh [2].
d) Encourages Soil-borne pathogens like nematodes: When a transition from PTR to DSR occurs, nematodes with root knots present a significant challenge. The most destructive soil-borne disease affecting aerobic rice is the root-knot nematode, or RKN, which lowers yields. Meloidogyne graminicola, a nematode that causes knots in roots, was initially discovered in 1963 at Louisiana State University in Baton Rouge, USA Kaur and Singh [2].

e) Increased nitrous oxide emissions: Aerobic soil conditions can raise N2 O emissions while direct seeding can aid in lowering CH4 emissions. Kaur and Singh [2].
f) Nutritional disorders, particularly those involving N and micronutrients: micronutrient deficiencies are a major cause for concern in DSR. Rice's zinc availability decreases when PTR to DSR transition occurs because less zinc is released from highly insoluble fractions in aerobic rice fields. Because of their reduced redox potential, anaerobic soils frequently have particularly high Fe availability Kaur and Singh [2].
g) Stagnant Yield: There have been reports of yield declines in DSR, which could be caused by a number of factors, including plant auto toxicity, soil illness, the presence of G. graminis var. graminis in dry-seeded rice fields, and continuously growing DSR for more than two years. Farooq et al*.,* [30].
h) Lodging: In comparison to PTR, DSR is more likely to lodge. The crop is harder to harvest due to lodging, which also lowers yield and degrades the rice's flavor and appearance. It is best to choose rice cultivars with lodging-resistant traits, such as medium plant heights, wide stem diameters, thick stem walls, and high lignin content Kaur and Singh [2].
i) Diseases and insect pests: DSR is prone to a number of diseases, of which rice blast is one of the most prevalent. Damage resulting from rice blast escalates in situations of water stress because the water level influences a number of processes, including the release and germination of spores and infection in rice that causes blast. Water management affects the crop microclimate, particularly dew deposition, which creates an environment that is conducive to host susceptibility. Other disease and insect issues reported in DSR include plant hoppers, brown spot disease, sheath blight, and dirty panicle. Additionally, soil-borne pathogenic fungus Gaeumannomyces graminis var. graminis has been found in dry-seeded rice in Brazil without additional irrigation Kaur and Singh [2] and Farooq (et al*.,* [30].

3.3 Innovations for Promotion of DSR

Now a day, The DSR technology has been sincerely promoted by a number of National, International, and Private Organizations. Breeders, agronomists and agricultural engineers have also concentrated their efforts in developing suitable cultivars, agronomic packages and need based implements for promoting the DSR. Some of the recent technological developments in the DSR are discussed below [1].

i. **Innovations for promotion of DSR**: Many international, national, and private organizations have been sincerely promoting the DSR technology in recent years. Breeders, agronomists and agricultural engineers have also concentrated their efforts in developing suitable cultivars, agronomic packages and need based implements for promoting the DSR. Some of the recent technological developments in the DSR are discussed below-
ii. **Zero tillage/reduced tillage:** In the entire IGP, zero tillage has been proven to be an economical, yield-boosting, and environmentally friendly resource conservation technique. The new generation zero till seed cum test planters for multiple crops that use disk type coulters enable seeding even in the presence of both loose and anchored residue [31,32].
iii. **Laser land leveler:** Traditionally, leveled fields may have variances from the average elevation of the fields of up to ± 6 cm or more, even though they appear even. The field surface is smoothed to within ± 2 cm with laser leveling. According to the results of farmer-initiated trials, precision land leveling with laser assistance saved at least 15 cm of water in rice-wheat systems and increased yield by up to 25%. Precision leveling increased cultivable area by 3-6% by removing numerous field bunds and irrigation channels, and it reduced or eliminated weed problems in the initial years [33,34].
iv. Leaf colour chart (LCC) for N application the results showed that real-time LCC (LCC = 3 for basmati rice and LCC = 4 for hybrid and high yielding medium fine to coarse grain rice) N management could improve the agronomic efficiency of N in rice. Its use saved N up to 17% in transplanted rice without any yield penalty [35].
v. **Weed management:** Low productivity in rice crops that are directly seeded is primarily caused by weeds. Based on DSR

data, it has been observed that a pre-emergence application of pendimethalin (1 kg ha^{-1}) dissolved in 500–600 L of water and a post-emergence application of a ready mix of chlorimuron + metsulfuron (4 g ha^{-1}) for weed control of broad leaves and sedges, or ethoxysulfuron (15 g ha^{-1}) for sedges and broad leaves, or 2,4–D (5 g ha^{-1}) applied approximately 20 days after sowing for broad leafed weeds, and Fenoxaprop (50 g ha^{-1}) for grassy weeds, have been found to be effective in increasing rice grain yield.. Azimsulfuron is also doing a good job of managing the intricate weed flora in the Indo-Gangetic Plains DSR.

3.4 Future Perspective

The system has shown to be both affordable and farmer-friendly, but in order to reap the full benefits, technological advancements must be made. The following ideas are proposed for policy makers, extension agents, and scientists to take into account [1,24].

i. Further investigation is required to develop high-yielding rice cultivars that are appropriate for DSR in various agroclimatic circumstances. Variety must have the desired characteristics, such as fast growth, the capacity to suppress weeds, the ability to germinate in the presence of moisture stress, and tolerance to micronutrient deficiencies.
ii. Due to insufficient nutrient inputs, ineffective water management, and issues with weed control, DSR productivity is low and needs to improved.
iii. The timely establishment of DSR crops between mid-May and mid-June, or 15-20 days prior to the start of the monsoon, is important to the crop's success. At the time of sowing, irrigation water must be available.
iv. A cooperative society with a cluster of villages for ensuring the availability of agri-inputs, laser land leveler, zero till machine, LCC, cono-weeder at reasonable costs needs to be strengthened
v. The type and quantity of weed, the low-cost integrated weed management technology, which uses the stale seed bed technique, appropriate aerobic genotypes, cultural, physical, mechanical, and low-dosage herbicide applications for various ecosystems across different regions, needs to be fine-tuned.
vi. When direct seeding rice, the issue of weedy rice arises, particularly in areas that are irrigated by canals. It is imperative that a strategic approach be taken to combat this threat.
vii. Due to the high level of technicality involved in herbicidal application, rice growers must receive training on sprayer calibration, herbicidal spray preparation, the value of flat fan/flood Jet nozzles, herbicidal application technique, and herbicidal spray precautions.

4. CONCLUSION

In situations where labor and water are scarce, DSR remains a viable alternative to TPR and can produce yields that are comparable to TPR with the right agronomic interventions. It has been reported that unmanaged weeds in the field can reduce DSR yield by up to 75%. An effective weed-monitoring program is necessary, and various weed-management strategies—such as crop-competitiveness, which can be improved by growing suitable cultivars and adjusting seed rate, row spacing, nutrient and water management, and cultural weed management through stale seedbed and crop residue mulch—are needed. Enhanced NUE, efficient weed control, and a deeper comprehension of disease-pest interactions will all help to maximize DSR yields. Since rice production is being threatened by climate change, increased labor costs, water scarcity, and other issues, questions about alternatives are undoubtedly emerging. It is a workable substitute for TPR that has the potential to reduce labor costs, water, energy use, and the effects of climate change. About 34% less labor and 50% less water are used. Therefore, DSR is the most practical way to achieve sustainable yields without overusing the natural resources that are already available when the future of rice production is threatened by the current global water shortage and rising labor costs.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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