Resilience through Innovation: The Impact of Direct Seeding on Water Use Efficiency and Rice Productivity

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ABSTRACT

Rice (*Oryza sativa*) is the major food crop in terms of production, economy and grown in all ecological regions. In Asia, particularly in the tropical regions, transplanting is the predominant method of rice establishment. This method is highly input and water intensive, raising concerns about long-term sustainability. Climate change, especially in the form of water scarcity, poses a significant threat to traditional rice cultivation. Direct-Seeded Rice (DSR) has emerged as a viable and resource-efficient alternative to the traditional puddled transplanted rice (TPR) system, particularly in the context of increasing labour scarcity, water limitations and the need for sustainable agricultural practices. DSR bypasses nursery raising and transplanting, allowing rice seeds to be sown directly in the main field. This approach significantly reduces water usage, labour demand and greenhouse gas emissions, while

enhancing soil health and profitability. Precise water management, particularly during crop emergence phase (first 7-15 days after sowing), is crucial in direct seeded rice. Furthermore, weed infestation is the major problem, which can cause large yield losses in direct seeded rice. Weed management in DSR can be done through chemical, hand weeding or stale seed bed method.

INTRODUCTION

Rice (*Oryza sativa* L.) is a vital staple food crop for more than four billion people across the globe (Yuan *et al*., 2021). In India, rice plays an indispensable role in the diets of around 800 million people. India stands as the second-largest producer of rice globally, trailing only behind China (Bhattacharya, 2022). Key rice-producing states in India are primarily found along riverbanks, such as West Bengal, Bihar, Punjab, Uttar Pradesh, Haryana, Odisha, Chhattisgarh, Telangana, Tamil Nadu, Andhra Pradesh, Kerala and Assam, among others. The state of Punjab has notably thrived in rice cultivation over the past six decades, commencing with the Green Revolution of the 1960s. Often referred to as the "Rice Bowl of India," Chhattisgarh have significantly contributed to India's rice production. India dedicates approximately 43 million hectares to rice cultivation, resulting in an impressive 112 million metric tons of milled rice with an average yield of 2.6 metric tons per hectare

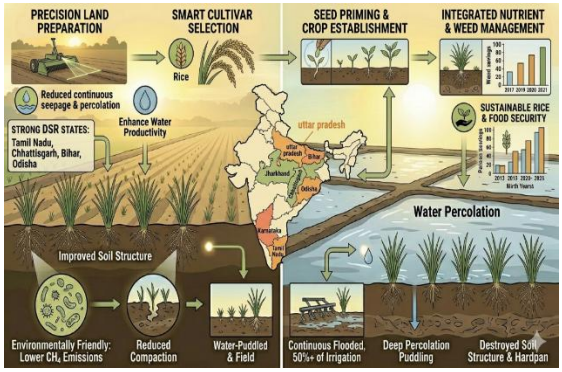
Rice is also one of the most water-intensive crops, consuming over 50% of the irrigation water used in agriculture. Climate change, especially in the form of water scarcity, poses a significant threat to traditional rice cultivation. Declining water table and degrading soil health are the major concerns for the current growth rate and sustainability of Indian Agriculture (Bhattacharyya *et al*., 2015). In conventional systems, around 60–83% of the water applied to paddy fields is lost through deep percolation. Given the increasing constraints on land and water resources, enhancing rice productivity through sustainable and water-efficient technologies has become a pressing need for the Indian agriculture (Kumar, *et al*. 2022).

To address these challenges, water-saving rice cultivation methods such as aerobic rice, the System of Rice Intensification (SRI), and dry direct-seeded rice (DSR) have emerged as promising alternatives. These methods can reduce water usage by 20-60% compared to traditional transplanting methods (Nayak *et al*., 2020). Among them, DSR offers significant potential for enhancing water use efficiency, reducing labour dependence, and ensuring timely crop establishment and making it highly relevant for improving the resilience and productivity of rice-based systems in the Indian agriculture.

DSR TECHNOLOGY

Direct-Seeded Rice (DSR) is a crop establishment technique where rice seeds are sown directly into the main field, bypassing the traditional practice of raising and transplanting seedlings from nurseries. This approach significantly reduces continuous seepage, percolation losses, enhances water productivity, labor input, energy consumption, and greenhouse gas emissions. By eliminating raising of seedlings in a nursery, puddling, and transplanting, DSR can save up to 20-60% compared to puddled transplanted rice (TPR) (Bhandaria *et al*., 2020). Moreover, it enables faster crop establishment due to avoidance of transplanting shock, and promotes earlier physiological maturity, helping the crop

escape late-season drought (Tuong, 2008). Historically, direct seeding is one of the oldest methods of rice cultivation practiced by humans. In India as well, DSR has a long-standing presence and has seen a steady rise in adoption in recent years. Its relevance is particularly evident in states with irregular rainfall patterns and soil moisture limitations, such as Tamil Nadu, Jharkhand, Chhattisgarh, parts of Bihar, Odisha, Karnataka, and eastern Uttar Pradesh (Singh *et al*., 2021). These regions show strong potential for scaling up DSR as a climate-smart and resource-conserving technology.



DSR offers a promising shift towards resource-efficient and climate-resilient rice production systems.

1. Dry direct-seeded rice

In dry direct-seeded rice (D-DSR), dry seeds are sown directly into the main field without prior germination. This method is commonly used in rainfed uplands, medium lowlands, lowlands, and deepwater ecologies during the wet season. Weed control is a major challenge in D-DSR, but it can be effectively managed with post-emergent herbicides. This method offers several benefits, including up to 20-60% water savings compared to conventional transplanted rice and a reduction in methane (CH_4) emissions by 18-20%. Additionally, D-DSR reduces labor requirements, enhances seedling emergence, and decreases the risk of lodging (Nayak *et al*., 2020).

2. Wet direct-seeded rice

W-DSR involves sowing of pre-germinated seeds (radicle 1- 3 mm) on or into puddled soil through manual broadcasting or tractor-drawn drum seeder. When pre-germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic W-DSR. When pre-germinated seeds are sown/ drilled into puddled soil, the seed environment is mostly anaerobic and this is called anaerobic W-DSR. When proper management practices are followed, the yield of Wet-DSR is comparable to that of transplanted rice. Additionally, Wet-DSR increases water productivity by 0.3 to 0.4 kg rice m^{-3} water (Nayak *et al*., 2020).

3. Water seeding

Water seeding is typically practiced in irrigated lowland areas with standing water depths of 5 to 15 cm. The field is dry-ploughed and harrowed without puddling, after which pre-germinated seeds are broadcasted into 10 to 15 cm of standing water (Chaudhary *et al*., 2023).

BENEFITS OF DSR

1. **Reduced Labor Costs:** DSR technology reduces labour requirement by 30–40% due to elimination of nursery raising, uprooting, and transplanting, hence is especially beneficial in areas with labour shortages or high wage rates (Farooq *et al*., 2011).

2. **Faster Crop Establishment:** Direct Seeded Rice technique enables quicker crop establishment, resulting in earlier and faster rice plant development. DSR promotes early crop establishment, which reduces the risk of yield loss due to late season drought and minimizes the need for costly additional irrigation. This method also helps protect soil structure (Singh *et al*., 2023). This method Shortens the crop duration by 7–10 days due to absence of

transplanting shock. Hence, Facilitates timely sowing of succeeding crops like wheat or pulses.

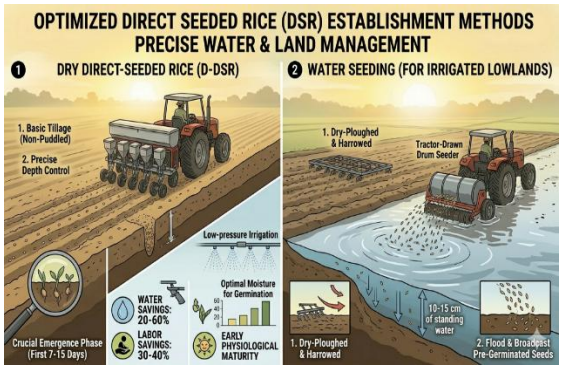
3. **Improved Water Use Efficiency:** DSR uses 25–35% less water compared to puddled transplanted rice (TPR) by avoiding puddling and continuous flooding.

4. **Environmentally Friendly:** DSR technology is environmentally friendly, as it reduces the use of chemicals and other inputs associated with traditional methods of rice cultivation. Reduces methane (CH_4) emissions due to aerobic soil conditions. Suitable under variable monsoon conditions and low water availability.

5. Improved Soil Health: DSR technology helps to improve soil health by reducing soil compaction and promoting microbial activity as it avoids puddling, which destroys soil structure and creates a hardpan.

6. Increased Profitability: By reducing labor costs, improving yields, and reducing the need for inputs, Direct Seeded Rice technology can increase the profitability of rice cultivation.

7. Positive effect on succeeding crop: The soil structure is improved through direct seeding, which creates a favourable environment for succeeding crops by preventing continuous puddling from destroying the soil structure.



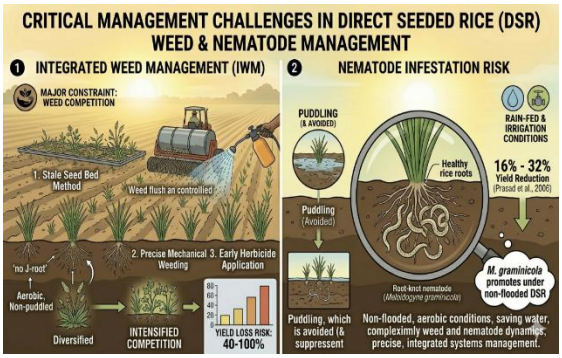
CONSTRAINTS OF DSR

1. **Poor seedling establishment:** In the DSR system, farmers often face challenges in achieving uniform crop establishment compared to conventional puddled transplanting. This is largely due to the use of basic or inadequate land preparation practices. Poor seedling emergence is a common problem in direct seeding (Farooq *et al*., 2011).

2. **Weed competition:** Weeds are among the most serious biological constraints in DSR, especially on light-textured soils, causing significant economic losses. Weeds can cause yield loss ranging from 40% to as high as 100% if not managed timely. Unlike puddled transplanted rice, where early flooding suppresses weed emergence. Moreover, weed populations in DSR are more diverse and aggressive compared to those in transplanted systems (Rao *et al*., 2007), increasing the crop's vulnerability to weed pressure.

3. **Nematode infestation:** When employing the DSR cultivation technique, specific soil-borne pathogens, particularly nematodes, have been discovered to be active. DSR will likely promote an increase in the root-knot nematode (*Meloidogyne graminicola*) in the rice root zone, thereby decreasing rice yield (Sekhon *et al*, 2023).

Proper management of weeds, water, and nutrients emerges as a key factor for successful DSR adoption, reflecting the need for more precise input usage in modern rice.



CONCLUSION

Direct-Seeded Rice (DSR) holds considerable promise for transforming rice cultivation in India by addressing the twin challenges of water and labour scarcity while enhancing sustainability. Compared to the conventional TPR system, DSR offers multiple benefits like reduced water and energy use, lowered methane emissions, enhanced profitability and improved soil structure. However, the technology is not without challenges. Effective management of weeds, nutrients and soil-borne pests like nematodes is crucial for maximizing the potential of DSR. It is not just a method of rice establishment but a transformative approach towards climate-smart agriculture. With the right support and adaptive management, DSR can play a pivotal role in ensuring sustainable rice production and securing food and livelihood security in India's future agricultural landscape.

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