NRRI Research Bulletin No. 50

DIRECT SEEDED RICE: A Technology for Enhancing Climate Resilience

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Correct Citation

Kumar A, Verma R L, Sah R P, Satapathy B S, Mohanty S, Tripathi R, Chattopadhyay K, Samantaray S and Nayak A K (2024). Direct Seeded Rice: A Technology for Enhancing Climate Resilience. NRRI research Bulletin No. 50, ICAR-National Rice Research Institute, Cuttack-753006, Odisha, India. pp-32.

Published by

Director
ICAR-National Rice Research Institute
Cuttack-753006, Odisha, India

August 2024

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Printed in India at Print-Tech Offset Pvt. Ltd., Bhubaneswar, Odisha 751 024.

PREFACE

The shift towards more sustainable and resource-efficient agricultural practices is becoming increasingly important in the face of global challenges such as water scarcity, labor shortages, and climate change. In this context, Direct Seeded Rice (DSR) has emerged as a promising alternative to traditional puddled transplanting methods. DSR offers numerous advantages, including reduced water usage, lower labor requirements, and enhanced profitability. However, the adoption of DSR comes with its own set of challenges that need to be addressed to realize its full potential.

ICAR-National Rice Research Institute (NRRI), Cuttack, has been at the forefront of research and innovation in rice cultivation, including the advancement and promotion of DSR techniques. Recognizing the growing challenges of water scarcity, labor shortages, and the need for sustainable agricultural practices, NRRI has made significant contributions to the development and adoption of DSR in India. Through its research, development of new varieties, mechanization efforts, and extensive outreach programs, NRRI has made a significant impact on the adoption of DSR in India. These efforts continue to pave the way for more resilient and resource-efficient rice farming, ensuring food security and environmental sustainability for future generations.

This research bulletin on DSR explores the key factors influencing the success of DSR, including the availability of suitable rice varieties, effective weed and pest management, the role of modern machinery, and the importance of policy and institutional support. We also examine the socio-economic impacts of DSR adoption and provide insights into how farmers can overcome common barriers to implementation.

As we move towards a future where sustainable agriculture becomes increasingly vital, we hope this bulletin will contribute to the wider understanding and adoption of DSR. By equipping stakeholders with the knowledge and tools necessary to implement DSR effectively, we can work together to ensure that rice farming remains productive, resilient, and environmentally sustainable.

We would like to express our gratitude to all the researchers, practitioners, and farmers who have contributed to the development of this bulletin. Their insights and experiences have been invaluable in shaping the content of this publication. We also acknowledge the support of various institutions and organizations that have made this research possible.

We hope that this bulletin will inspire and guide further research, innovation, and action in the field of DSR, ultimately contributing to a more sustainable and food-secure world.

AUTHORS

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1. Introduction

Rice, a semi-aquatic crop, adapts its growth patterns to thrive in various habitats. It is primarily cultivated using either transplanted or direct-seeded agronomic systems. The transplanted rice system, although effective, is more input-intensive, requiring additional water, which raises sustainability concerns, and also contributes to methane emissions and excessive use of non-renewable energy. In contrast, the Direct Seeded Rice (DSR) system promotes more efficient use of water and nitrogen, reduces greenhouse gas emissions, and lowers labour demand, thereby avoiding the drawbacks associated with the transplanted system. Once a common practice before the Green Revolution in India, DSR is regaining popularity due to its significant water and labour-saving benefits.

Direct Seeded Rice is a viable alternative to conventional puddled transplanted rice, with strong potential to mitigate and adapt to climate change. This system empowers poor farmers to better cope with climate-induced changes by providing flexible rice establishment methods and reducing the water needed for both crop establishment and growth. Additionally, in the event of early drought, farmers can opt for direct seeding with minimal soil moisture, rather than waiting for adequate rainfall to begin transplanting. 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.

Despite its potential benefits, the DSR system faces significant challenges, particularly severe weed infestations, with some weeds being very difficult to control. To address these issues, it is crucial to provide farmers with information on herbicide resistance management strategies and the importance of crop rotation. Improper use of herbicides can lead to the development of herbicide-resistant weed species, which can have devastating effects on production costs and yields. Many farmers are unfamiliar with the various types of herbicides and their proper application techniques. Additionally, a large number of farmers are not well-versed in DSR technology, leading to difficulties in sowing and achieving good crop establishment.Early sowing of DSR, typically from the end of May to June, can sometimes lead to challenges in harvesting the crop during September-October due to heavy and frequent rains. Moreover, marginal and fragmented landholdings present a significant barrier to the adoption of mechanized sowing methods in DSR. Water shortages and reliance on rainfall or canal water further complicate timely sowing efforts.

In DSR, seeds can be sown directly into fields where crop residues have been retained, using advanced seeding machines. This approach reduces the need for rice straw burning, which is harmful to the environment as it releases suspended particles and smoke that can cause respiratory issues like asthma. Additionally, DSR reduces the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide, which contribute to global warming. The elimination of transplanting also lessens the physical strain on female farm labourers. Overall, DSR enhances system productivity and lowers cultivation costs by approximately Rs. 5000-6000 per hectare.

Thus, rice cultivation requires ongoing efforts to develop a resource-efficient and sustainable alternative system that can address the challenges of climate change and other emerging risks. DSR represents a viable alternative, as it has the potential to produce higher yields with less labour while ensuring optimal water use in an environmentally friendly manner.

2. Direct Seeded Rice

Direct Seeded Rice is an establishment method where rice seeds are sown directly into the main field rather than transplanting seedlings from a nursery. This can be done either by sowing pre-germinated seeds into puddled soil (wet direct seeding) or into a well-prepared non-puddled seedbed (dry direct seeding). A significant challenge with DSR, particularly dry DSR, is weed infestation, which can lead to yield losses of up to 85% if not properly managed. Seed priming with water and KCl has shown promise in improving crop establishment.

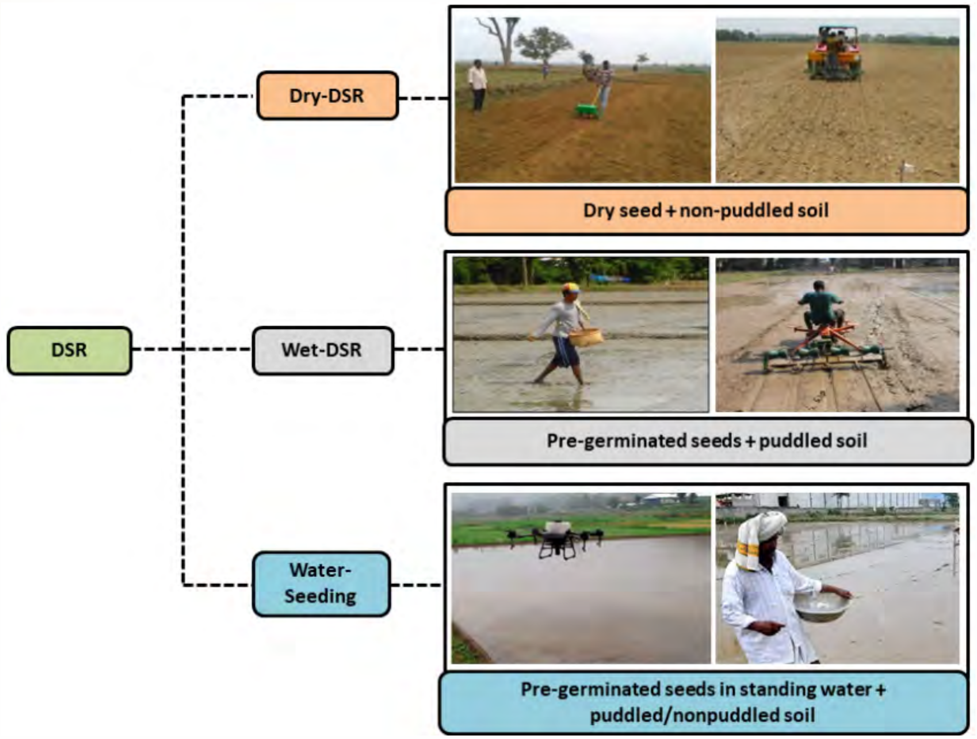

Fig. 1 Types of DSR
(Photo Source: Author's own compilation)

a) 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 30% 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).

b) Wet direct-seeded rice

This practice is recommended when a late onset of monsoon rains delays timely sowing. By applying irrigation water and using sprouted seeds, farmers can sow the crop on time through the direct seeding method, which uses less water compared to traditional transplanting. 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. Suitable varietal traits for DSR cultivation

Cultivars play an important role in crop-weed competition because of morphological features, canopy structure and relative growth rate. A quick-growing and early canopy cover enables cultivars to compete better against weeds. Short-duration varieties adaptive under aerobic conditions is most suitable for DSR cultivation. Cultivars suitable for DSR conditions should have traits for anaerobic germination, early vigour and weed competitiveness, Lodging resistance, Nutrient responsiveness and Nematode tolerance.

a) Anaerobic germination

Anaerobic germination enables rice seeds to germinate and grow in low-oxygen environments. This trait is particularly valuable for direct-seeded rice systems, where seeds are often subjected to water stagnation after sowing due to unpredictable rain. The AG1 and qAG7 QTLs have been identified as key regulators of anaerobic germination, allowing rice seeds to survive and thrive in anaerobic environments. Developing rice varieties with enhanced anaerobic germination capacity can significantly improve crop establishment in flood-affected regions, reducing seedling mortality and ensuring successful crop production under challenging conditions (Yang et al., 2019). Some of the varieties and landraces tolerant to anaerobic germination are CR Dhan 414, CR Dhan 215, FR13A, Swarna Sub1, CR-2862-IC-10, CR 2851-S-1-B-4-1-4- 1-1, KPH-481 Plus (Hyrid), Dular, Bina Dhan 7, IR64 Sub1, Karuppukavuni, Kalanamak, CO55 and Chitiraikar.

b) Early vigour and Weed Competitiveness

Seedling vigor is important for weed competitiveness in DSR, where rice seedlings and weeds germinate simultaneously. The traits will help in a natural weed suppressant where rice varieties establish quickly to outcompete weeds. Traits associated with rapid early growth, governed by QTLs like qSV-6a associated with root length, qVI linked to seedling vigor index and qGP-6 related to germination percentage and other several QTLs were identified (Yamasani et al., 2023), Besides deeper root system not only stabilizes the plant but also enhances its ability to absorb water and nutrients from the soil, contributing to better plant health and yield. The DRO1 gene controls root growth angle, allowing roots to penetrate deeper into the soil. Similarly, OsNAC10 is involved in the regulation of root development under stress conditions, enhancing drought tolerance (Uga et al., 2013). Researchers have identified several QTLs associated with root length and architecture in rice (Kitomi et al., 2018). Some of the varieties and landraces with early vigour and weed competitiveness are Mahasuri, Sabita, Sahabhagidhan, Vandana, Arize 6444, Arize Dhani and Swarna Shreya, Rajalaxmi, CR Dhan 702, CR Dhan 703, CR Dhan 307, CR Dhan 212 and CR Dhan 312.

c) Lodging resistance

One of the major challenges affecting its productivity under DSR is lodging, which leads to substantial reductions in both grain yield and quality. Lodging causes decreased photosynthesis and nutrient transport, primarily due to stem bending. It typically occurs when the weight of the plant's upper part, including the panicle, causes the stem to bend towards the ground, especially under the stress of heavy rain, storms, or high planting densities. In tropical conditions, especially in irrigated and deep-water rice systems, lodging can result in yield losses of up to two tons per hectare. Recent advancements in breeding for lodging resistance in rice have highlighted several key genes and quantitative trait loci (QTLs) that contribute to enhanced culm strength and structural integrity.The gene OsPSLSq6 (Os06g0623200), QTLs such as SCM1 and SCM2 have been identified for inducing culm strength (Rashid et al., 2022). Some of the varieties and landraces with lodging resistance are CR Dhan 312, CR Dhan 321, Padmini, Sarala, CR Dhan 702, 703, 704, Sabaur Heera

d) Nutrient responsiveness

Nitrogen (N) and phosphorus (P) use efficiency are critical factors in the productivity of rice, especially under DSR conditions, where nutrient availability can significantly impact crop performance. Enhanced nitrogen and phosphorus use efficiency in rice can lead to reduced fertilizer inputs, lower production costs, and minimized environmental impacts. Several genes and quantitative trait loci (QTLs) have been identified that are associated with improved nitrogen and phosphorus use efficiency.For nitrogen use efficiency, QTLs such asOsGRF4 enhances NUE, OsDof1 associated with N uptake, NADH-GOGATInfluences N assimilation, OsNPF6.1, OsNRT2.3b, OsNRT2.1 plays roles in N transport, OsPTR9 linked to N utilization and DEP1 affects yield and NUE

(Kumari et al., 2021).Phosphorus use efficiency is also crucial for rice grown under DSR. The PSTOL1 gene (Phosphorus Starvation Tolerance 1), located on chromosome 12, has been identified as a major QTL associated with improved phosphorus uptake efficiency. PSTOL1 enhances root growth, enabling rice plants to access phosphorus more effectively from the soil, which is particularly beneficial in low-phosphorus conditions (Gamuyao et al., 2012). Some of the varieties and landraces with high nitrogen use efficiency are CR Dhan 319 , CR Dhan 308, CR Dhan 310, Tella Hamsa, DRR Dhan 64, IR 64, Nidhi, Tapaswini, IRRI 154, Pusa 44, Koshihikari, SL8H, IR36. Some of the varieties and landraces with high phosphorus use efficiency are CR Dhan 801, DRR Dhan 60, DRR Dhan 65, DRR Dhan 66, Telangana Vari 8, Pusa Basmati 1121, BRRI Dhan 29, IC 467627, IC 426097and IC 277228.

Iron and zinc deficiencies are common issues under DSR conditions, where soil dynamics differ from traditional transplanting methods. Iron is an essential micronutrient for rice, playing a crucial role in photosynthesis and respiration. Iron deficiency typically manifests as interveinal chlorosis, stunted growth, and reduced yield. The gene OsIRO2 has been identified as a key regulator in iron uptake and homeostasis. OsIRO2 encodes a basic helix-loop-helix (bHLH) transcription factor that enhances the expression of genes involved in iron absorption from the soil. Overexpression of OsIRO2 has been shown to improve iron uptake in rice, making it a promising candidate for breeding iron-efficient varieties suitable for DSR systems (Ogo et al., 2007). Zinc is another critical micronutrient influencing several physiological processes, including enzyme activation, protein synthesis, and growth regulation. The OsZIP (Zinc-regulated transporter, Iron-regulated transporter-like Protein) family of genes, especially OsZIP1 and OsZIP3, play significant roles in zinc uptake and transport within the plant (Ishimaru et al., 2005). Some of the lines with low fe tolerance are RA23 , Prabhavati, Rudrama.

e) Nematode tolerance

Nematodes, particularly the root-knot nematode (*Meloidogyne graminicola*), pose a serious threat to rice grown under DSR by attacking the roots and impairing water and nutrient uptake. Resistance to nematodes in rice is complex and polygenic. *M. GRAMINICOLA-RESISTANCE GENE 1* (*MG1*), an *R* gene highly expressed at the site of nematode invasion, determines resistance against the nematode in several rice varieties. Introgressing *MG1* into susceptible varieties increases resistance comparable to resistant varieties (Wang et al., 2023). Some of the varieties and landraces with nematode resistance are ASD-16, Vanaprava, Khanika, Udaya, Basmati 370, Jogen, Dinesh, Pusa 1637-18-7-6-20, Manik, Abhisek, Pratikhya, BAS-63, BBSR Local-2, Udaya, FR-13-A and Keshari.

f) Drought Tolerance

Breeding programs focus on developing varieties that can maintain productivity under drought conditions. This involves selecting traits like root architecture, osmotic adjustment, and stomatal conductance, which contribute to improved drought tolerance.

The QTLs qDTY1.1: identified for the drought-tolerant aus cultivar N22, qDTY1.1 and qDTY3.1 significantly affects grain yield under drought and qDTY12.1 identified for drought tolerance. The variety Shabhagidhan, CR Dhan 801, CR Dhan 802, IR 64 drt etc. showed superior performance under drought and possess drought QTLS. SNAC1 (Stress-Responsive NAC 1): SNAC1 is mainly induced in guard cells by drought stress. It binds to the promoter of another gene called OsSRO1c (similar to RCD one) and activates its expression. OsSRO1c, in turn, participates in the regulation of stomatal aperture (which controls water loss) and oxidative stress tolerance (You et al., 2023). Some of the varieties and landraces with drought tolerance are Sahabhagidhan, IR64dr, CR Dhan 103, CR Dhan 107, CR Dhan 108, CR Dhan 807, CR Dhan 801, CR Dhan 802, CR Dhan 804 and the varieties released for aerobic situation also have some low moisture stress tolerance ability.

Incorporating genes/QTLs into new rice varieties allows breeders to develop plants with rapid establishment and strong early seedling vigor, reducing competition from weeds and minimizing the need for labor and chemical inputs. Selecting traits like vigorous root systems enhances resilience to water stress, ensuring stable yields even in challenging conditions.These genetic advancements helps to develop rice varieties to handle challenges such as iron and zinc deficiencies and nematode infestations under DSR systems, contributing to more sustainable and productive rice farming.

4. Suitable rice varieties for DSR cultivation

a) Varieties for DSR under Upland

Direct Seeded Rice technique is also becoming popular in upland conditions, where traditional transplanting methods can be less effective due to various environmental and logistical challenges. Upland areas often experience irregular rainfall patterns and limited water resources, making traditional puddled transplanting difficult. DSR requires less water than transplanting because it eliminates the need for continuous flooding. This method allows farmers in upland regions to make more efficient use of available water, especially in rainfed conditions. In upland conditions, where the growing season may be limited by the onset of dry periods or other climatic factors, DSR can offer an advantage due to the potential for earlier sowing and shorter crop duration. This enables farmers to harvest earlier and avoid late-season drought stress.

Despite its advantages, the adoption of DSR in upland conditions also comes with challenges. Effective weed management remains critical, and the lack of standing water in DSR fields can lead to higher weed pressure. Additionally, the success of DSR in upland areas depends on appropriate seedbed preparation, timely sowing, and the selection of suitable rice varieties that can thrive in non-puddled, direct-seeded environments. ICAR-NRRI has developed varieties suitable for upland conditions like: CR Dhan 100, CR Dhan 101, CR Dhan 103, CR Dhan 107, CR Dhan 807, CR Dhan 808, Phalguni.

b) Varieties for DSR under Medium land

Medium lands are characterized by moderate water availability and relatively flat or gently sloping terrain, which makes them well-suited for DSR. Medium land areas typically have better water retention than uplands but may not have the continuous water supply necessary for traditional transplanting methods. DSR is well-suited for these conditions as it requires less water compared to puddled transplanting. By adopting DSR, farmers can optimize water use, especially in areas where water is available but not abundant enough to sustain flooded conditions throughout the growing season.Medium land conditions often allow for flexibility in the timing of agricultural operations. DSR can take advantage of this by allowing farmers to sow seeds earlier than they could transplant seedlings. This can help in avoiding peak labor demand periods and taking advantage of early rainfall, ensuring that the crop establishes itself before potential dry spells. If an irrigation facility is available, varieties of medium duration (120-135 days) are well suited. Some of the varieties developed by ICAR-NRRI suitable for medium land conditions like: CR Dhan 200, CR Dhan 201, CR Dhan 202, CR Dhan 203, CR Dhan 204, CR Dhan 205, CR Dhan 206, CR Dhan 211, CR Dhan 212, CR Dhan 214, Naveen, CR Dhan 321, CR Dhan 308, CR Dhan 314, CR Dhan 328, CR Dhan 312, CR Dhan 704, CR Dhan 212, CR Dhan 805 and CR Dhan 307.

c) Varieties for DSR under Lowland

Lowland areas are often subject to climatic extremes such as heavy rains or droughts. DSR can be advantageous in these conditions because it allows for a more flexible sowing window. For example, in areas prone to early-season floods, DSR can be delayed until after the risk of flooding has passed. Conversely, in drought-prone areas, DSR can be sown early to take advantage of available moisture. Varieties with long maturity duration (135 -150 days) are most suited for DSR under lowland conditions. ICAR-NRRI has developed varieties suitable for lowland conditions like: CR Dhan 802, CR Dhan 317, Pooja, CR Dhan 414 and CR Dhan 702.

5. Agronomic management practices for DSR

5.1. Land preparation and sowing

a) Precision land levelling

Laser land levelling serves as a precursor technology and a crucial entry point for the success of DSR by enhancing water management, weed control, and overall crop management.

An uneven soil surface can disrupt drill operations, leading to poor crop establishment and performance, primarily due to adverse nutrient-water dynamics and increased weed competition.Uneven land hinders seed placement and germination, while also demanding


Fig. 2. Field levelling by Laser leveller
(Photo Source: Author's own collection)

more power for machinery, which results in higher energy consumption, increased production costs, and lower productivity. Ineffective management and uneven fields can cause a 10-25% loss of irrigation water during application (Kahlown et al., 2007), leading to reduced crop yields, increased irrigation costs, and lower resource-use efficiency (Jat et al., 2006).Traditionally, farmers level the land using plankers (wooden boards) pulled by tractors. Fields levelled this way often have numerous dikes and ditches, and despite the best efforts with conventional methods, field slopes still range from 1º to 3º (Jat et al., 2006). This variation in slope contributes to the poor establishment of direct-seeded rice crops.

Precision land levelling enhances rice performance in non-puddled soil, particularly when using no-till surface seeding or seeding on permanent beds, compared to conventional tillage. Additionally, if rain occurs immediately after seeding, laser-leveled fields facilitate better emergence due to adequate drainage.

b) Suitable soil type

Heavy-textured soils are ideal for DSR cultivation due to their lower deficiencies in iron (Fe) and zinc (Zn) compared to light-textured sandy soils, which is crucial as Fe and Zn deficiencies are significant challenges for DSR crop establishment. Light-textured soils, on the other hand, have low water retention capacity because of their high infiltration rate. In the DSR system, the effectiveness of sowing methods and pre-emergence herbicides is significantly influenced by soil type.

In medium-textured soil, sowing should be carried out in dry conditions followed by immediate irrigation. Moist conditions generally develop 3 days after sowing (DAS), so pre-emergence herbicides should be applied within this timeframe. Conversely, in heavy-textured soil, moist conditions may not develop within 3 DAS if irrigation is done immediately after dry seeding. Thus, it is advisable to sow the crop in moist conditions and apply pre-emergence herbicide immediately after sowing to take advantage of the available moisture and improve herbicide efficacy.

c) Sowing time

In Direct Seeded Rice, sowing the crop at the optimal time is crucial for achieving high water productivity. Vigorous early growth before the onset of monsoon rains helps reduce seedling mortality due to submergence. Additionally, early and robust crop development facilitates the timely harvesting of rice and subsequent planting of wheat, ensuring an efficient and productive cropping system. Early sowing of the crop, such as in May, may lead to increased water requirements and can result in poor establishment. This is because early planting often coincides with higher temperatures and potentially less favourable moisture conditions, which can affect seedling growth and establishment.

To effectively utilize monsoon rains, the optimal sowing time under DSR is generally 10–15 days before the onset of the monsoon. Planting before the rains begin helps avoid the challenges of wet soil, which can hinder machinery movement and make seeding more difficult. Additionally, if rains persist for several days, the risk of seed rotting and seedling mortality due to submergence increases, leading to poor crop establishment. Delayed sowing leads to poor emergence, reduced heading panicles per square meter, fewer spikelets per panicle, and ultimately affects the yield negatively.

Wet -DSR is recommended when a late monsoon delays sowing. By applying irrigation water and sprouted seeds, farmers can ensure timely planting through the direct seeding method, which consumes less water than traditional transplanting.

d) Sowing depth

The critical nature of seeding depth in DSR is influenced by the mesocotyl length of different rice varieties. Semi-dwarf varieties generally have shorter mesocotyls compared to conventional tall varieties, which makes proper seeding depth essential for optimal germination and growth. Sowing seeds at either too deep or too shallow a soil depth can negatively impact the germination process. This is primarily due to the weaker coleoptiles, which struggle to reach the surface if planted too deep, and the rapid drying of the soil surface during peak summer, which can hinder proper seedling emergence (Gopal et al., 2010).To ensure uniform crop establishment, rice should not be sown at a depth greater than 2.5 cm. Sowing beyond this depth can lead to issues with seedling emergence and overall crop uniformity (Basra et al., 2005).

Wet -DSR involves sowing pre-germinated seeds (with radicles 1-3 mm long) on or into puddled soil, either through manual broadcasting or with a tractor-drawn drum seeder. When these seeds are sown on the surface of puddled soil, the seed environment remains mostly aerobic, known as aerobic W-DSR. However, when the pre-germinated seeds are sown or drilled into the puddled soil, the environment around the seeds becomes mostly anaerobic, which is referred to as anaerobic W-DSR.

A recent study at ICAR-NRRI, Cuttack, identified rice varieties with shorter plant heights, longer coleoptiles, and the ability to emerge from greater depths. This characteristic makes such varieties potentially suitable for direct seeding. However, ongoing breeding efforts are focused on developing DSR cultivars that can achieve uniform establishment even when sown at depths greater than 2.5 cm.

e) *Seed sowing using machinery*

A seed drill is a crucial tool used in the direct seeding of rice systems, where rice is sown directly into the soil without the need for prior transplanting. The seed drill allows for precise placement of seeds at a uniform depth and spacing, which is essential for achieving even germination and crop establishment. The seed drill is equipped with a seed metering mechanism that ensures the accurate distribution of seeds in each row. This prevents seed wastage and ensures optimal plant population.

Fig. 3. Direct Seed Sowing by Seed Drill
(Photo Source: Author's own collection)

One of the most critical aspects of a seed drill is its ability to adjust the seeding depth. In DSR, the recommended seeding depth is typically around 2.5 cm. The adjustable mechanism allows for precise depth control, which is crucial for the germination success of rice varieties with shorter coleoptiles.The seed drill also provides control over the spacing between rows, which is important for the aeration and overall health of the rice crop. Proper row spacing can help in managing weeds, reducing competition, and ensuring sufficient sunlight penetration. After the seeds are placed in the soil, the seed drill's covering mechanism ensures that they are adequately covered with soil, which protects them from being exposed to birds, pests, or harsh environmental conditions.

Fig. 4.Seed filled in Seed Drill
(Photo Source: Author's own collection)

Many modern seed drills come with an integrated fertilizer application system. This feature allows for the simultaneous placement of seeds and fertilizer, ensuring that the nutrients are available to the seedlings from the start, which can enhance early growth and establishment.

Implements used in Wet-DSR are specialized tools designed to optimize the sowing process in this innovative method of rice cultivation. One of the primary tools is the drum seeder, which allows for uniform and precise placement of pre-germinated rice seeds directly into the wet field, ensuring optimal plant spacing and reducing seed wastage.

Fig. 5 Mechanical wet DSR (Photo Source: Nayak et al., 2020)

Challenges:

Skill Requirement: Operating a seed drill requires technical knowledge and skill, particularly in calibrating the machine for different soil conditions and rice varieties.

Initial Investment: The cost of purchasing and maintaining a seed drill can be a significant investment for small-scale farmers, although it often pays off through increased efficiency and yield.

f) Seed rate

Application of high seed rate in rice cultivation can cause nitrogen deficiency, increase in ineffective tillers, more susceptible to brown planthopper infestations, and raise the likelihood of crop lodging, which may ultimately contribute to a significant reduction in grain yield. For healthy crop establishment and maximum yield potential, an optimal seed rate of 20–25 kg per hectare has been identified for medium-fine-grain rice cultivars,with a recommended spacing of 20 cm between rows and 5 cm within rows (Gopal et al., 2010).

Lowering the seed rate in DSR has broadened the potential for its use, making it a more versatile and cost-effective option for farmers. This approach can help lower input costs for farmers, especially when using hybrid rice seeds. It's important to note that achieving lower seed rates in DSR requires a seed drill equipped with a seed metering device to ensure accurate and efficient seed placement.

g) Seed treatment and seed priming

Seeds play a crucial role in crop production, and effective seed treatments are essential for enhancing germination, ensuring uniform seedling emergence, and protecting seedlings from soil and seed-borne pests. Seed treatments involve various physical and chemical processes to protect seeds from soil-borne pathogens and boost the presence of beneficial microorganisms in the plant's rhizosphere, which promotes growth.

Seed priming is a specific hydration technique where seeds are soaked in water or a low osmotic chemical solution and then re-dried to their original state. This process initiates germination-related metabolic activities without triggering radical emergence. Both seed treatment and seed priming improve seedling performance under challenging conditions such as extreme temperatures, low moisture and excess moisture. Priming rice seeds has been shown to enhance crop establishment and subsequent growth. Priming resulted in larger leaf areas, taller plants, and increased root and shoot dry weights measured four weeks after sowing. Additionally, primed seeds produced significantly more tillers, panicles, and grains per panicle (Warda, 2002).

Different types of seed priming are:

Hydro priming: It involves soaking seeds in water for a specific period. This technique is particularly beneficial for dryland farming. Hydro priming enhances seed vigor, improves germination percentage, increases water use efficiency, and promotes uniform seedling growth.

Halo priming: It involves soaking seeds in solutions of salts like NaCl or KCl. This technique helps improve germination and seedling vigor under challenging conditions such as salinity, anaerobic environments, and high temperatures (Nayak et al., 2020).

Osmo priming: It involves soaking seeds in an osmotic solution such as potassium nitrate, polyethylene glycol (PEG), mannitol, sorbitol, or glycerol. This method improves germination by allowing the seeds to begin metabolic activities without initiating full germination, enhancing overall seedling establishment (Nayak et al., 2020).

Bio-priming: It involves treating seeds with inoculums of beneficial microorganisms combined with regulated seed hydration. This method enhances the seeds' ability to withstand both biotic (e.g., pathogens) and abiotic (e.g., drought, extreme temperatures) stresses, thereby improving seedling growth and resilience. (Bisen et al., 2015)

Hormonal priming: It involves treating seeds with various hormones to promote seedling growth and development. Commonly used hormones in this process include abscisic acid, auxin, ethylene, gibberellins, polyamines, kinetin, and salicylic acid. These hormones help enhance germination rates, seedling vigor, and overall plant health (Nayak et al., 2020).

5.2. Nutrient Management Strategy for DSR

a) Dose and timing of fertiliser application

Precision nutrient management is becoming important in rice and other cropping systems to enhance productivity (Dobermann and Witt, 2004; Sapkota et al., 2016). This approach not only reduces the overuse of fertilizers but also significantly reduces greenhouse gas emissions. Proper dosage, timing, and method of application are crucial in nutrient management for rice. If not managed correctly, it can result in the loss of reactive nitrogen through denitrification, volatilization, and leaching. These losses are particularly significant in dry-DSR systems, where they tend to be higher compared to Transplanted Rice (Davidson, 1991).As a result, the availability of essential plant nutrients such as nitrogen (N), phosphorus (P), potassium (K), sulfur (S), iron (Fe), and zinc (Zn) is reduced (Ponnamperuma, 1972), which can impede optimal plant growth and yield in DSR. However, several fertilizer management practices can enhance nutrient availability in DSR, thereby supporting better plant development and yield.

Table 1. Fertiliser recommendations for different ecologies under DSR

Land type	**Fertiliser dose (kg/acre)**			**Time of application**
	N	P	K	
Medium and rainfed low land	24	12	12	❖ Basal full dose P, K & 25% N at 14 DAS ❖ 50% N at Maximum Tillering ❖ 25% N at Panicle Initiation
Irrigated	32	16	16	❖ Basal full dose P, K & 50% N at14 DAS, ❖ 25% N atMaximum Tillering ❖ 25% N at Panicle Initiation
Low land where top dressing is not possible	16	8	8	❖ Full dose of N, P & K fertilizer as basal dose

The nitrogen fertilization dose in DSR is typically higher than that in Transplanted Rice to compensate for the greater losses of reactive nitrogen (Gathala et al., 2011). In DSR, it is common practice to apply one-third of the full dose of nitrogen, phosphorus, and potassium as a basal dose. This approach improves fertilizer use efficiency by ensuring that essential nutrients are readily available to the plants from the early stages of growth. The remaining two-thirds of the nitrogen dosage is applied in equal splits during the vegetative (active tillering) and reproductive (panicle initiation) stages of growth (Kamboj et al., 2012).This method of fertilizer application enhances grain yield and maximizes nitrogen use efficiency. Phosphorous solubilizing bacterial culture @ 25 g kg^{-1} is recommended to enhance availabilityof P in soil, whereas integration of 50% recommended dose fertilizer + Gliricidia @ 2.5 t ha^{-1} + Phosphate Solubilizing Bacteria @ 2.5 kg ha^{-1} +Azotobactor @ 2.5 kg ha^{-1} is recommended for autumn rice.

b) Real-Time Nitrogen Management

Real-time nitrogen management in DSR is crucial for optimizing crop yield and ensuring sustainable farming practices. Unlike traditional transplanted rice, DSR plants have different growth patterns and nutrient uptake dynamics, making precise nitrogen management essential. By applying nitrogen based on real-time crop needs farmers can avoid both under and over-application of this critical nutrient. Proper nitrogen management enhances plant health, promotes efficient growth, and leads to higher yields. In essence, real-time nitrogen management in DSR contributes to better crop performance, cost savings for farmers, and environmental protection.

ICAR-NRRI, Cuttack has developed a Customised Leaf Colour Chart (CLCC) for need-based nitrogen fertilizer application in rice. To do this, compare the color of the youngest fully expanded leaf (second from the top) of 10 randomly selected, disease-free rice plants with the CLCC color strips every 7-10 days, starting from 6 weeks after sowing until flowering begins. If 6 or more of the 10 leaves are less green than critical CLCC value, apply another split dose of nitrogen. If 6 or more of the leaves are greener than critical CLCC value, you can skip the nitrogen application at that time.

Fig. 6. Nitrogen management through CLCC (Photo Source: Nayak et al., 2020)

To monitor and determine the leaf N content and record real time N fertilizer requirements to synchronize the demand and supply of the rice crops, ICAR-NRRI, Cuttack developed a smart android based application (riceNxpert) for leaf color monitoring and N recommendation suitable for different rice ecologies.

Fig. 7. Nitrogen management through riceNxpert (Photo Source: Nayak et al., 2020)

c) *Green/brown manuring*

In DSR, the use of chemical nitrogen fertilizer can be significantly reduced by incorporating green or brown manuring, such as Sesbania (Farooq et al. 2021). Sesbania seeds, @ 19.76 kg ha^{-1}, are broadcast three days after rice sowing and are allowed to grow for 25–30 days. After 25–30 days, the Sesbania is dried by spraying 2,4-D. In the case of broadcast rice, during the beushening period, the harvested Sesbania foliage is incorporated into the soil.This practice provides approximately

Fig. 8. Green manuring (Photo Source: Nayak et al., 2020)

14 kg of nitrogen per acre, adds organic matter to the soil, and contributes to overall soil health.Thus, a part of nitrogenous fertilizer (upto 25%) can be replaced by brown manuring.

d) *Micronutrient management:*

Micronutrient deficiency is often observed in DSR due to the lack of reduced conditions in the soil. Symptoms of Fe deficiency in DSR include interveinal chlorosis of new leaves, reduced dry matter production, and, in severe cases, complete chlorosis and death of the plant. To address this, it is advisable to grow iron-efficient cultivars. Additionally, managing Fe deficiency can be achieved by adding organic matter and applying a foliar spray of 1% ferrous sulfate or ferrous ammonium sulfate.

Zinc deficiency in DSR typically becomes evident 4-6 weeks after sowing, characterized by dusty brown spots on the upper and middle leaves, uneven plant growth, chlorotic midribs, decreased tillering, and reduced leaf blade size. When deficiency symptoms are observed, 10-25 kg per hectare of $ZnSO_4 \cdot 7H_2O$ is applied. For emergency treatment, a foliar spray of 0.5-1.0 kg Zn per hectare, using a 0.5-1.0% $ZnSO_4$ solution in about 200 liters of water per hectare, is applied.

5.3. Weed management strategy under DSR

Weed infestation poses a major challenge to the broad adoption of DSR. In transplanted rice, seedlings gain a 3-4 week advantage over weeds, minimizing the threat of weed infestation. Conversely, in DSR, weeds and rice seeds sprout at the same time, resulting in strong weed-crop competition. Grassy weeds are especially troublesome in DSR. Therefore, adopting integrated weed and water management strategies, along with the selective application of herbicides, is crucial to managing these weeds effectively.

There are various weed management strategies available, and it is essential to incorporate as many as possible, depending on the location and resource availability, for sustainable weed control in DSR.

a) *Manual weeding*

Many farmers depend on manual labor for weed removal. To maximize yields, it is essential to control weeds early, as most damage occurs when both the crop and weeds are still small. However, the timing of weeding often depends on labor availability, which may not coincide with the optimal time for effective weed control. Weed removal equipment can damage rice plants, particularly during early growth stages, and may struggle to distinguish between grassy weeds and rice, leading to potential accidental removal of rice plants. Moreover, hand weeding is significantly more costly—at least five times more expensive—than using herbicides for weed control in wet-seeded rice. In dry–DSR, hand weeding should be reserved for specific weeds that were not managed by pre- or post-emergence herbicides.

b) Mechanical weeding

Mechanical weeding, such as incorporating weeds in situ, can aid in the effective recycling of depleted nutrients. While rotary weeders are effective in controlling weeds in the inter-row spaces, they often struggle to manage weeds in the intra-row spaces or those close to the crop.

Mechanical weeding with a rotating hoe equipped with small toothed wheels improves soil aeration by increasing soil pores, allowing roots and microbes better access to oxygen. This process also significantly boosts tiller production (Randriamihariosa 2002).

Farm mechanization is a highly effective method for efficient weed control. The mechanization of weeding operations for rice crops, particularly on small land holdings, has been addressed, and suitable weeding implements like Finger weeder, Wheel finger weeder, Cono weeder and Blade and Rake weeder have been developed by ICAR-National Rice Research Institute, Cuttack. Implements like the conoweeder help save labor and time by reducing the number of man-days required for weeding. The use of a conoweeder led to a 10% increase in grain yield during the wet season, while the yield increase was only 3% higher in the dry season compared to conventional weeding methods (Parida and Das 2004).

c) Chemical weed control

In general, cultural and mechanical methods of weed control are time-consuming, cumbersome, and labor-intensive. Additionally, they are often less effective due to the possibility of weeds escaping or regenerating from roots or rhizomes that are left behind. The morphological similarity between the crop and certain grassy weeds further complicates hand weeding. As a result, the use of herbicides emerges as the most viable alternative. Given the increasing labor challenges, herbicides are becoming an increasingly preferable option for farmers.However, herbicides should not be seen as replacements for other weed control practices but should be used alongside them. Herbicide application should be timed to coincide with sufficient weed presence to justify treatment and should be done when weeds are most vulnerable. The optimal herbicide rate depends on factors such as cultural practices, soil type, and environmental conditions. Researchers at ICAR-NRRI, Cuttack, recorded the highest weed control efficiency (95.2%) with the application of bensulfuron methyl @ 60g ha^{-1} at 20 DAS. Significantly higher number of panicles per m^2 (268) and grain yield (4.79 t ha^{-1}) were recorded with application of metsulfuron methyl @ 8g ha^{-1} (Saha and Rao 2009; Saha and Rao, 2010). Recommended herbicides for dry direct seeded and wet direct seeded rice is shown below:-

Table 2. Recommended Herbicide for Dry direct-sown rice (Rainfed uplands and lowlands)

Sl. No.	Name	Target weeds	Time of Application	Dose (g a.i. ha^{-1})
1.	Bispyribac Sodium (Nominee gold)	Early emergent grassy weeds and few sedges	8-10 days after sowing (DAS)/ OR at 2-3 leaf stage of weeds	30
2.	Fenoxaprop-p-ethyl (Rice star)	Late emergent grassy weeds	15-20 DAS/ OR at 3-5 leaf stage of weeds	60
3.	Cyhalofop-butyl (Clincher)	Grassy weeds	15 DAS/ OR at 2-4 leaf stage of weeds	100
4.	Ethoxysulfuron (Sunrise)	Sedges and borad-leaved weeds	15 DAS/ OR at 2-4 leaf stage of weeds	20
5.	Fenoxaprop-p-ethyl + Ethoxysulfuron (Tank-mix)	Mixed weed population	15-20 DAS/ OR at 3-4 leaf stage of weeds	50+15

Adapted from Saha et al., 2018

Table 3. Recommended Herbicide for Wet direct-sown rice (Rainfed shallow lowlands and irrigated)

Sl. No.	Name	Target weeds	Time of Application	Dose (g a.i. ha^{-1})
1.	Bispyribac Sodium (Nominee gold)	Early emergent grassy weeds and few sedges	10 days after sowing (DAS)/ OR at 2-3 leaf stage of weeds	30
2.	Bensulfuron methyl + Pretilachlor (Ready-mix-Eraze-Strong/Londax power)	Mixed population of weeds	7 DAS	10 kg ha^{-1}
3.	Ethoxysulfuron (Sunrise)	Sedges and borad-leaved weeds	15 DAS/ OR at 2-4 leaf stage of weeds	20
4.	Metsulfuron methyl + chlomuron ethyl (Ready-mix-Almix)	Sedges and borad-leaved weeds	15-18 DAS/ OR at 3-4 leaf stage of weeds	4

Adapted from Saha et al., 2018

d) *Herbicide Tolerant Rice*

Weed infestation can cause yield losses of 18–48% in rice. Weeds are managed either by maintaining stagnant water in the field or through manual or mechanical weeding. Availability of cost-effective weed control methods is crucial for making rice cultivation economically viable and sustainable.In addition to broadleaf and grassy weeds, weedy rice has become an emerging problem under direct-seeded conditions. Weedy rice competes intensely and traditional herbicides often fail to control it, as those that do kill weedy rice may also harm the rice crop. Therefore, there is a need to develop rice varieties that can control both weedy rice and other weeds.

Fig. 9 CR Dhan 807 in field
(Photo Source: Author's own collection)

In India, scientists have successfully developed a mutant line, 'Robin,' in the upland variety N22 that tolerates the herbicide Imazethapyr due to a mutation in the Acetohydroxy Acid Synthase (AHAS) gene. At ICAR-National Rice Research Institute, this herbicide-tolerant gene has been introduced into four popular rice varieties (Sahbhagidhan, Naveen, Swarna Sub1, and Pooja). Researchers at NRRI, Cuttack have identified rice cultivar tolerant to the herbicide Imazethapyr (CR Dhan 807) for release in six states (Jharkhand, Odisha, Chhattisgarh, Gujarat, Andhra Pradesh and TamilNadu).When sprayed 21 days after sowing, Imazethapyr effectively controls both rice weeds and weedy rice without affecting the yield potential of the tolerant variety. The release and widespread adoption of herbicide-tolerant rice could significantly reduce cultivation costs and expand the acreage of direct-seeded rice in India.

5.4. Irrigation management

Because of variations in moisture levels and puddling techniques, the soil's physical, chemical, and biological properties differ significantly between DSR and puddled rice.Irrigation scheduling is the application of irrigation water with respect to time and space based on the crop's evaporative demand. One of the major objectives of DSR is to ensure higher water productivity in rice cultivation. Irrigation scheduling for DSR is typically done using methods such as saturated soil culture (SSC), alternate wetting and drying (AWD), tensiometer-based irrigation, and critical stage-based life saving irrigation.

Fig. 10. Eco-friendly Irrigation alert system installed in field
(Photo Source: Author's own collection)

Researchers at ICAR-NRRI, Cuttack have developed sensor-based irrigation scheduling tools/implements for enhancing water productivity under DSR. ICAR-NRRI has developed Eco-friendly Irrigation Alert System, in which a sensor is attached to the perforated pipe installed in the rice field at the desired depth. The sensor is connected to a microcontroller and relay module. A 12V battery powers the whole system and the battery is charged by a solar panel installed at the top of the structure. As soon as the water level in the rice field goes down below the desired level, the sensor communicates the signal to the microcontroller, which switches on the red bulb and alarm system. The glow of the red bulb and alarm sound aware the farmer of the irrigation event. Moreover, on reaching the threshold level, the microcontroller and GSM modem also send an alert message to the farmer's mobile number registered with the system. This system runs on clean energy (solar power), hence, it eliminates the necessity for electricity. This system alerts the end user through SMS, light, and sound alarms and thus it facilitates effective monitoring of real-time water levels in the field. It has the potential to save around 30% of irrigation water without having any negative impact on grain yield. Thus, it increases the water productivity by 40%. It also increases net return for farmers by reducing pumping costs and fuel consumption. It also curtails the methane emission from rice fields by around 37% (Kumar et al 2022).

In the Alternate Wetting and Drying (AWD) method of rice irrigation, effective scheduling can also be based on soil water potential, measured by a tensiometer. ICAR-NRRI has developed a simplified, farmer-friendly version of the tensiometer tube for real-time irrigation scheduling based on soil water potential (Kumar et al., 2021; Tripathi et al., 2021). In this version, the traditional measuring gauge is replaced by colored stripes:

light blue, deep blue, orange, and brown. When the water level in the tensiometer tube is at the light blue stripe, there is no need for irrigation. Irrigation is necessary when the water level reaches the deep blue stripe. Entry into the orange and brown stripes indicates a risk to crop yield, which should be avoided. Irrigation scheduling using this tensiometer is reported to save approximately 30% of irrigation water compared to the continuously flooded method (Kumar et al., 2017a, 2021).

Fig. 11. Customised Color Coded Tensiometer installed in field
(Photo Source: Nayak et al., 2021)

The water productivity and other benefits of improved irrigation methods, such as Alternate Wetting and Drying (AWD), System of Rice Intensification (SRI), and Tensiometer-based irrigation, practiced at Tangi block, Cuttack, are presented in Table 4. The water productivity of the flooded irrigation treatment was the lowest at 0.25 kg/ m^3, compared to all the climate-smart water management methods implemented (Nayak et al., 2021).

Table 4. Water productivity of rice under different irrigation regimes

Treatments	Grain yield (t/ha)	Water used (mm)	Water productivity (kg/m^3)	% of water saved over flooding
Flood	4.14	1610	0.25	-
AWD	4.63	1099	0.42	31.73
Tensiometer	4.14	1140	0.36	29.19
SRI	5.35	1119	0.47	30.49

Adapted from Nayak et al., 2021.

6. Greenhouse gas emissions under DSR

Direct-seeded rice provides non-puddled soil conditions, resulting in higher water percolation rates, increased soil macro-porosity, and improved soil pore continuity. These factors enhance gas diffusivity and increase methane (CH_4) oxidation. In contrast, in transplanted rice with continuous flooding (TPR-CF), the puddled conditions restrict water percolation and create anaerobic conditions, which are conducive to CH_4 emissions (Kumar et al., 2019). In flooded puddled rice with continuous flooding (FPR-CF), anoxic conditions are produced, enabling methanogens to generate CH_4 through the anaerobic decomposition of organic materials.

Research findings from ICAR-NRRI, Cuttack showed that methane emission was lower in all DSR demo plots under wet/dry and zero tillage conditions than under the conventional TPR. The emissions were even lower under dry- DSR than under wet and/or zero tillage DSR. Careful land and water management in DSR with proper sequence of wetting and drying has the potential to reduce significant methane by 40– 50%.

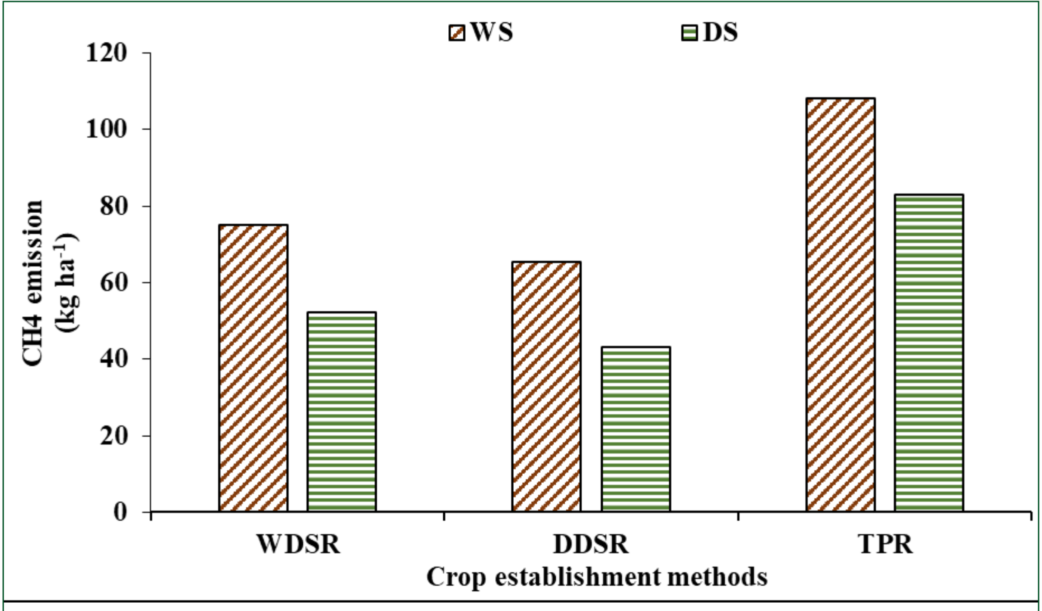

Fig.13. Effect of different DSR on methane emissions

WDSR– wet direct seeded rice, DDSR– dry direct seeded rice, TPR– transplanted puddled rice. Source: Authors analysis of research data from Resilience project sites.

7. Economics of DSR

The cost of farming is influenced by various factors such as wages for labor, equipment utilization, and expenses for irrigation. The profitability of DSR varies across different areas. Regions with lower labor costs and convenient access to irrigation water generally show a higher benefit-cost ratio when using DSR compared to other areas. Several research studies have highlighted the significant economic advantages associated with DSR (Pandey and Velasco, 2002). The costs involved in cultivating under DSR are reduced by 45-48% compared to TPR, mainly due to more efficient crop establishment and water management methods (Yaduraju et al., 2021). The decrease in production costs under DSR increases profitability, primarily because of reduced tillage operations, lower labor and irrigation water costs, and increased use of machinery for various agricultural tasks (Tripathi et al., 2014). Assuming that other expenses for crop cultivation remain the same for both TPR and DSR, adopting DSR could result in a net saving of INR 9,114 to 10,192 per hectare. This implies that implementing DSR across one million hectares of land could generate an economic benefit of around INR 10.0 billion (Yaduraju et al., 2021). Incorporating a seed drill, power-operated boom sprayer, and combine harvester into the DSR system (made available to farmers through custom hiring centers) helped reduce cultivation costs by 25%. Moreover, the utilization of modern seed drills decreased the seed rate under DSR by about 50% compared to TPR (Dhakal et al., 2019).

Pilot demonstrations carried out by ICAR-NRRI, Cuttack at the Resilience project site in Odisha, India, revealed a significantly higher benefit-cost ratio for DSR compared to TPR. The use of seed drills in the DSR demonstrations notably lowered labor and fuel costs, consequently enhancing farm profitability.

8. Exploring challenges and implementing measures to upscale adoption of DSR

The practice of DSR is gaining popularity among rice farmers in areas with limited water resources. Globally, about 23% of rice-growing regions have adopted DSR (Kumar and Ladha, 2011). This adoption is also increasing in Southeast Asia’s rice-growing regions (Bhandari et al., 2020). The growing popularity of DSR is attributed to its benefits, including improved water use efficiency, reduced methane emissions, lower labor costs, increased net profits, and better maintenance of soil physical properties.

Despite the benefits, Indian farmers encounter several obstacles in adopting DSR. These challenges include a lack of climate-resilient rice varieties that match the performance of those used in puddled transplanted conditions, insufficient effective herbicides, problems with crop lodging, iron deficiency, nematode infestations, the unavailability of appropriate machinery for seeding rice, and a general lack of awareness about advanced DSR production technologies (Bhullar and Gill, 2020). Measures to overcome some of these challengesare discussed below:

Shortage of DSR adaptive varieties: The shortage of DSR adaptive varieties is a significant challenge affecting the widespread adoption of DSR practices. DSR involves sowing seeds directly into the soil without prior puddling, which requires rice varieties that can perform well under these specific conditions. Unfortunately, the limited availability of such varieties hampers the full potential of DSR. Addressing the shortage of DSR-adaptive varieties is critical for maximizing the benefits of DSR and ensuring its widespread adoption. With targeted research and strategic interventions, the development and availability of suitable rice varieties can significantly enhance the effectiveness and sustainability of DSR practices.

Lack of Effective Herbicides and Nematode Infestation: The effective management of weeds is crucial for the successful adoption of DSR. In DSR systems, weeds can be more challenging to control compared to traditional puddled transplanting methods due to the absence of water coverage, which usually suppresses weed growth. The lack of effective herbicides exacerbates this problem, making weed management a major concern.Without effective herbicides, managing the weed competition becomes labor-intensive and costly.

Nematodes are microscopic worms that can cause significant damage to rice crops, particularly in DSR systems where the absence of soil puddling can lead to higher nematode populations. Nematode infestations can adversely affect root health, nutrient uptake, and overall crop performance.Addressing the challenges of ineffective herbicides and nematode infestations is critical for the successful adoption of DSR. By investing in research, improving management practices, and providing support to farmers, these issues can be mitigated to enhance the overall effectiveness and sustainability of DSR systems.

Iron deficiency in DSR soils: Iron is a crucial micronutrient for rice plants, necessary for various physiological processes, including chlorophyll synthesis and respiration. In aerobic soils, iron tends to form insoluble compounds, making it less available for plant uptake. This reduced availability can lead to iron deficiency, characterized by chlorosis (yellowing) of the leaves.Addressing iron deficiency in DSR soils requires a combination of soil management practices, appropriate use of fertilizers and amendments, and the development of tolerant rice varieties. By implementing these strategies, the challenges of iron deficiency can be mitigated, leading to improved crop health and productivity in DSR systems.

Limited availability of specialized equipment for seeding rice: DSR requires specific machinery such as seed drills and precision seeding machines that are designed to handle dry or semi-dry soil conditions. These machines need to be able to plant seeds at the correct depth and spacing to ensure optimal germination and growth. In many regions, especially in developing countries, the availability of DSR machinery is limited. Even when DSR machinery is available, maintaining and repairing these machines can pose challenges. Access to spare parts, technical expertise, and service support may be limited, leading to downtime and reduced operational efficiency. Establishing custom hiring centers where farmers can rent DSR machinery can help mitigate the issue of high initial costs. This model allows farmers to access modern equipment without the financial burden of ownership.

Lack of Awareness on DSR Cultivation Methods: Addressing the lack of awareness about DSR cultivation methods is crucial for expanding its adoption and maximizing its benefits.Implementing field demonstrations and pilot projects in collaboration with local farmers can showcase the benefits and feasibility of DSR. Seeing successful examples can encourage other farmers to adopt the practice. Encouraging peer learning and knowledge sharing among farmers who have successfully adopted DSR can help spread awareness and build trust. Farmer-to-farmer networks can be effective in sharing practical experiences and insights. Partnering with agricultural research institutions, NGOs, and government bodies can facilitate the dissemination of information and resources related to DSR. Collaborative efforts can amplify outreach and support for DSR adoption.

9. Policy and institutional support for upscaling DSR

Policy and institutional support are crucial for the widespread adoption and upscaling of DSR systems. Effective policies and strong institutional frameworks can create an enabling environment that encourages farmers to transition from traditional rice cultivation methods to DSR, thereby maximizing the potential benefits such as water savings, reduced labor costs, and enhanced profitability.

Governments can offer subsidies for DSR-specific machinery, such as seed drills, or provide financial incentives to farmers who adopt DSR practices. These measures can reduce the initial costs and financial risks associated with transitioning to DSR, making it more accessible, especially for smallholder farmers. Policies promoting efficient water use can align with DSR adoption, as DSR is less water-intensive than traditional puddled transplanting. Supporting DSR through water-saving initiatives and incentives can encourage more farmers to adopt this method, particularly in water-scarce regions.

Establishing and supporting custom hiring centers where farmers can rent DSR-specific machinery can alleviate the financial burden of purchasing expensive equipment. Policies that promote the establishment of these centers, especially in rural and underserved areas, can facilitate the broader adoption of DSR.

Public-Private Partnerships can drive innovation, provide funding, and ensure the availability of quality inputs, such as DSR-adapted seeds and herbicides. Policies that encourage private sector involvement in DSR-related activities can enhance the availability of products and services essential for DSR adoption.

Ensuring that extension services are well-equipped to provide on-site demonstrations, field days, and hands-on training can help farmers see the practical benefits of DSR and learn how to overcome challenges associated with its adoption.

By creating an enabling environment through financial incentives, robust extension services, public-private partnerships, and farmer empowerment, governments and institutions can help overcome the barriers to DSR adoption. These efforts can lead to more sustainable rice production systems, improved farmer livelihoods, and greater resilience to the challenges posed by water scarcity and labor shortages.

Fig. 12. Hands on Training on Direct Seeded Rice
(Photo Source: Author's own collection)

10. Conclusions

The research bulletin examines the impact of DSR on various aspects of rice production in comparison to Transplanted Rice in different environments. It suggests that DSR could be a feasible alternative for rice production in response to challenges posed by drier and hotter climate conditions, provided that appropriate support is put in place.

The success of DSR relies on precise land leveling, high-quality drills with advanced seed-metering systems, and well-trained tractor and pesticide operators. It is critical to adjust seeding depth based on soil types and moisture levels. Tailoring cultivars for dry seeding is essential for increased productivity. Using herbicides before and after weed emergence is important for effective weed management, with the choice of herbicides depending on the dominant weed species. DSR is not impacted by transplanting shock and matures faster than transplanted crops, making it easier to integrate into various cropping systems. It also has the potential to replenish the groundwater table. Water savings in DSR depend on management practices, soil types, and other factors, and it's crucial to optimize water conservation without compromising yield due to water stress.

A collaborative effort is key to encouraging the adoption and expansion of DSR. Research should focus on developing rice varieties with early vigor and strong root architectures. Extension workers should increase demonstrations and provide training on DSR practices and their benefits. Policymakers and government agencies should provide support for the implementation and promotion of DSR in rice farming. Additionally, farmers who practice DSR should be incentivized for reducing greenhouse gas emissions through carbon credits.

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