Intercomparison of Mechanical Transplanted Rice and Direct Seeded Rice in Climate Change Resilient for Improving Crop-Water Productivity and Soil Health in North West IGP: A Review

Abstract:

Climate change is a major issue facing humanity, and the most common method for growing rice is manual puddled transplanted rice (PTR). Direct-seeded rice (DSR) is becoming increasingly popular due to its reduced methane emissions and reduced labour costs. However, there are drawbacks to this transition, such as an increase in weeds, herbicide resistance, nitrous oxide emissions, nutritional disorders, and soil-borne diseases. To reduce these issues, appropriate weed, water, and fertilizer management practices should be applied. Chemical and biotechnological methods, such as herbicide-resistant and more competitive allelopathic variants, will be required for sustainable rice production. The development of site- and soil-specific integrated packages will increase the adoption of DSR and decrease the negative effects of PTR on the environment.

Keywords: *Direct seeded rice, transplanted rice, wet-DSR, dry-DSR, GHG emissions*

Introduction:

Rice is typically transplanted using 4- to 6-week-old seedlings on well-tilled puddled soils under the traditional mode of rice production, known as mechanical transplanted rice (TPR). Using standing water to plough a field is known as puddling. Puddling causes a loss in soil permeability and anaerobic conditions. Standing water controls weeds by decomposing the weed seeds. The soil's softening facilitates transplanting. The loss through deep percolation is reduced as a result of the deposition of smaller soil particles, which plug the pores. Fe, Zn, and P become more available to plants under anaerobic conditions. Puddling and seedling transplanting use up about 30% of the total amount of water. Puddling breaks down soil aggregates and capillary pores, disperses clay particles (creating a crust on the surface of coarse-textured soil), and develops a hard pan that prevents successive crops from penetrating the soil deeply **(Haque *et al.,* 2016).** It worsens the physical state of the soil, raises bulk density, and lowers hydraulic conductivity. Puddling has many drawbacks, including physical harm and nitrogen loss (de-nitrification) under anaerobic conditions. According to **(Aslam *et al.,* 2002),** up to 30% of the irrigation water applied to the rice crop is used for puddling. Due to the disrupted soil structure caused by puddling, the energy needed to prepare the field for subsequent crops has increased **(Gill *et al.,* 2014).** When a dried puddled layer is ploughed under in fine-textured soils, large clods result. Before planting the subsequent crops, repeated cultivation is necessary to develop the fine tilth that will allow seed to soil contact. About 11% of the entire cost of producing rice is attributable to fuel costs, personnel costs, and equipment wear and tear during ploughing and puddling **(Rashid *et al.,* 2009).** Furthermore, conventional tillage causes the soil to emit greenhouse gases rather than absorb them **(Busari *et al.,* 2015).** To maintain the long-term production of rice, alternative rice establishment techniques, such as direct sowing, non-puddled transplanting, and minimal or no tillage, can be used. **(Ladha and Singh, 2009).**

Direct Seeded Rice

According to **Farooq *et al.* (2011),** direct seeded rice (DSR) is the method of establishing the crop from seeds sowed in the field as opposed to by transplanting seedlings from the nursery. This method lowers the overall water demand because it eliminates puddling and doesn't require constant immersion. Therefore, in the context of a changing environment, it is more appropriate to use the DSR technique (Table 1) for rice production as opposed to the traditional TPR.

Advantages of DSR

Earlier reports have noted a number of benefits of direct-seeding methods of establishment over transplanting. In addition to providing higher economic returns, the DSR technique of establishment is simpler, uses less labour and water, and is mechanization-friendly **(Bhushan *et al.,* 2007; Jehangir *et al.,* 2005).** Due to early flowering, DSR crops are said to have shorter crop cycles and mature seven to ten days earlier **(Farooq *et al.,* 2006).** Greenhouse gas emissions in DSR are lower than in TPR **(Balasubramanian and Hill, 2002).** As there are no growth delays caused by transplanting stress and injury, DSR typically establishes earlier than TPR. This helps the plant escape the late-season drought by hastening the plant's growth and development **(Tuong, 2008).** Due to the fact that dry direct seeding is done on dry fields, the overall water requirement has been significantly lowered **(Bouman and Tuong, 2001).** Because there are no problems caused by the presence of hard pan, successful crops can be grown comfortably. Because soil erosion and water shortages are a result of climate change, farmers will need to use water-saving technology like DSR **(Singh *et al.,* 2023).**

Disadvantages of DSR

DSR has a number of advantages over TPR, and while it is used in numerous settings with different modifications, it has not yet been widely accepted. DSR has a number of obstacles, including the lack of suitable cultivars, which causes irregular germination and a high death rate. Other significant problems include a severe weed infestation and the lack of an efficient post-emergence herbicide **(Singh *et al.,* 2005).** The expense of weed treatment is increased in DSR because to the relative higher weed infestation **(Rao *et al.,* 2007).** Similar to Zn and Fe deficiencies, high infiltration rates in DSR and an unbalanced fertiliser N application are to blame **(Gao *et al.,* 2006).**

Drivers of the Rice Direct Seeding Shift from Puddled Transplanting

Water Scarcity

Water is becoming a limited resource on a global scale. An alarming rate of groundwater table decline has been observed. On the other hand, traditional rice farming uses a lot of water. Water cannot be recreated, so it must be conserved and provided with enough drops. According to **Bouman and Tuong (2001),** up to 5000 L of water may be required to produce just 1 kilogramme of rough rice, which is considerably too much. According to **Barker *et al.* (2000),** rice uses two to three times as much freshwater as any other cereal, and according to **Carriger (2007), Tuong *et al.* (2005),** rice accounts for nearly 50% of all irrigation water utilised in Asia. According to data adjusted from **Gardner-Outlaw and Engelman (1997),** the amount of water available per person in India declined by 72.3% between 1951 and 2005 (5831 m3 and 1611 m3 in 1951 and 2015, respectively), and it is predicted to continue declining by 77.8% until 2050 (1292 m3 in 2050). Because of the growing population, falling water tables, diminishing water quality, ineffective irrigation infrastructure, and competition from non-agricultural industries, there is less water available. So, the adoption of direct sowing is motivated by water scarcity. There have been various attempts to identify alternatives to traditional PTR throughout the past ten years. **(Ladha *et al.,* 2009)** Enough water will be available for crop production thanks to excellent water management. The possibility of DSR as a substitute for PTR has been noted in numerous research. For instance, wet-DSR was found to save irrigation water during on-farm testing in the Philippines **(Tabbal *et al.,* 2002)** by an average of 67-104 mm (11–18%) while CT-PTR used the same irrigation application parameters. However, it was discovered in a different study carried out in the Malaysian Muda region by **Cabango *et al.* (2002)** that the application of irrigation water in dry-DSR was less by about 200 mm (40%) than CT-PTR.

Similar water savings of 10-15% have been reported in India using dry-DSR compared to CT-PTR when irrigation application criteria included the presence of hairline cracks or tensiometer-based (-20 kPa at 20-cm depth) tensiometers **(Bhushan *et al.,* 2007; Jat *et al.,* 2009; Sudhir-Yadav *et al.,* 2011).** DSR has a greater capacity for climate change adaptation than PTR since it uses less water and can withstand water stress better. In the near future, climate change is anticipated to increase the variability of rainfall as well as the risk of drought and water stress. Dry-DSR with minimal, decreased, or no tillage increases the potential of this technique by reducing labour costs in response to the developing water crisis **(Chaudhari *et al.,* 2015; Kaur and Singh, 2017).**

Soil Health

According to several studies **(Goptal *et al.,* 2010, Gupta *et al.,* 2006, Ladha *et al.,* 2009),** puddling has varying effects on the health of the soil (soil quality, particularly on soil physical properties), which is claimed to be another reason for the transition from CT-PTR to dry-DSR on ploughed soil (no puddling) or in ZT conditions, where an upland crop is grown after rice. Given that soil in the rice-wheat system experiences the wetting and drying phenomenon, this is particularly pertinent **(Ladha *et al.,* 2003).** Puddling dissolves soil aggregates, disperses small clay particles, eliminates capillary pores, and creates hard pan at shallow depths. Although puddling aids in weed management, greater water and nutrient availability, seedling transplantation, and establishment, it has a negative impact on the development and productivity of following upland crops **(Gathala *et al.,* 2011).**

Numerous research that examined how rice puddling affected subsequent wheat crops have been published. 28 of the 35 similar studies that **(Kumar and Ladha, 2011)** collected and assessed revealed negative effects of puddling on following wheat crop productivity. Only one study had good results for puddling, while five examples mentioned no influence. Location, soil type, rice establishment technique, number of crop cycles, rice yield, wheat yield, and the percentage of variation in wheat yield were the factors taken into account. The effectiveness of wheat was assessed in two medium-term trials conducted at Pant Nagar (5 years) and Modipuram (7 years), depending on whether it had received puddled or dry DSR. The Pant Nagar site was found to have 12% greater wheat yield in dry-DSR plots than in CT-TPR in each of the five years. At Modipuram, however, the wheat yield was constant for the first three years before increasing by 0.5–1.0 t/ha (9–25%) in the latter years in dry–DSR plots **(Gathala *et al.,* 2011).** Poor root development caused by the previous rice crop's puddling was the key factor in the reduced grain yield of wheat following CT-PTR **(Aggarwal *et al.,* 1995; Boparai *et al.,* 1992; Chenkual and Acharya, 1990).** Similar to this, **(Gangwar *et al.,* 2008; Gangwar *et al.,* 2008)** contrasted the productivity of the DSR-based cropping system and the PTR-based cropping system. He noted that the productivities of the DSR-wheat, DSR-chickpea, and DSR-mustard systems were greater than those of the PTR systems (13.53 t/ha, 12.12 t/ha, and 11.81 t/ha, respectively). Although it is clear that puddling is advantageous to the rice crop, it is also harmful to the growth and productivity of the following crop because it negatively impacts soil health **(Mishra *et al.,* 2018; Srivastava *et al.,* 2016).** Therefore, it is crucial to develop alternatives to puddling. The areas where there is less water availability and where crops are cultivated following rice farming should receive more attention.

GHG Emission

Increased rainfall intensity, which is known as the main cause of floods, as well as destruction and devastation to agricultural productivity and farmer life are all results of the influence of global warming on the environment **(Ghadi *et al.,* 2020).** Global warming is a result of greenhouse gas emissions, primarily CO2, CH4, and N2O, which are emitted as a result of agriculture. Crop production is responsible for 27% of food emissions, according to data from the meta-analysis by **Joseph Poore and Thomas Nemecek (2018),** which was published in science. The production of crops for human consumption accounts for about 21% of the emissions from these foods, whereas the production of crops for animal feed accounts for 6%. This includes things like the release of nitrous oxide from fertilisers and manure, carbon dioxide from agricultural equipment, and methane emissions from rice cultivation. They are the direct emissions that come from agricultural output. Cropping systems based on rice are important. GHG emissions from rice fields, mostly CO2 and CH4, are significant and dependent on management techniques. As a result, rice is a key crop for reducing GHG emissions **(Wassmann, 2004).** With 155 million acres of land under cultivation, rice is one of the three most important crops in the world. By 2025, India's growing population will consume 25% more rice **(Matloob *et al.,* 2015).** Punjab, India, the "food bowl of India," produces 50% of the country's rice in the Indo-Gangetic Plain in Northern India. Puddled transplanting is the most typical method of rice growing in the IGP. Because of the anaerobic soil conditions caused by prolonged flooding, this culture of flooded rice is the main source of methane emissions. According to **Houghton (1996), Reiner (2000),** this is responsible for 10–20% of all worldwide methane emissions. Because there is a lack of oxygen, C molecules are reduced to CH4 in waterlogged soils. The presence of standing water in traditional rice fields limits the amount of oxygen that may reach the soil. Methanogens, a tiny but specific bacterial group, deplete the soil's oxygen content and create anaerobic conditions. Therefore, conventional PTR, where standing water conditions are maintained during the crop growth, has considerable methane emissions. On the other hand, anaerobic conditions are not produced in DSR fields since they are not perpetually immersed under water. Methane emissions are hence minimal **(Pathak *et al.,* 2013). (Pathak *et al.,* 2013)** carried out a 2-year field experiment in the Jalandhar district of Punjab, India, to measure the potential of DSR with TPR for reducing GHG emissions and saving water and labour. He discovered that the GWP of CO2, CH4, and N2O was 2.91 t/ha on average in TPR and 1.94 t/ha in DSR. Another finding was that the conversion of the entire TPR state to DSR would result in a 33% decrease in GWP. Additionally, with DSR, 3–4 irrigations were avoided while maintaining production. When compared to TPR, DSR used 58% fewer tractors and 45% fewer workers. This demonstrates that DSR can be a workable substitute for PTR for mitigating and adapting to climate change while also raising farmers' income by lowering GHG emissions, water use, and labour (both human and machine) without reducing yield **(Pathak *et al.,* 2013).** The Indonesian Agricultural Environment Research Institute (IAERI), located in Central Java, Indonesia, carried out a similar study. According to **(Susilawati *et al.,* 2019),** CH4 emissions were 47% lower in DSR than PTR. Under DSR, GWP decreased by 46.4% without a material yield loss. Numerous studies comparing the CH4 emissions from various tillage and crop establishment methods with comparable water management strategies found that wet or dry-DSR had lower CH4 emissions than CT-PTR (8–22% or 24–79%, respectively) **(Kumar & Ladha *et al.,* 2011).** ZT-dry-DSR is 20% more effective than CT-TPR at reducing GWP, according to **(Ishibashi *et al.,* 2009). (Pathak *et al.,* 2009)** performed simulations for Indian circumstances and discovered that, in comparison to CT-TPR, dry-DSR on raised beds or ZT can reduce CO2 equivalent per hectare by 40–44%. According to **(Harada *et al.,* 2007),** switching from puddling to zero tillage resulted in a 42% decrease in GWP in Japan. From study to study, CH4 emissions differ, even in CT-PTR. According to **Aulakh *et al.* (2011),** the cause may result from the individual or combined effects of meteorological conditions, edaphic variables, and water management. As a result, it may be said that DSR is more effective at reducing GHG emissions, particularly CH4 **(Cassman, 1999)** if suitable crop management techniques are used. The dissimilatory nitrate reduction to ammonium (DNRA) route can also shield NO3 from leaching losses and reduce N2O emissions under DSR **(Pandey *et al.,* 2020).**

Conclusion:

To successfully switch from traditional flooded rice cultivation to improved resilient rice agriculture, production must be increased. Resilient rice production techniques with improved crop establishment procedures, improved water, weed, and nutrient management approaches, and exploitation of microbial resources have been shown to be particularly beneficial in water-stressed locations and for farmers with limited resources. Stress-relieving microorganisms have the potential to boost agriculture's sustainability globally and get us closer to the ideal position of agriculturally producing nations by preserving the productivity and stability of agro-ecosystems. It is difficult to control biotic and abiotic pressures in rice, which calls for the development of climate-smart bacteria to lessen climatic extremes. Rice's general productivity and production potential can be increased by utilizing microbial resources and putting resilient rice farming techniques into practice.

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Direct Seeding Systems	**Condition of seed bed**	**Seed environment**	**Sowing method practiced**	**Ideal ecology/environment**
Direct seeding in dry bed (Aerobic rice)	Dry soil	Seeds are sown directly in dry and mostly aerobic soil	Broadcasting/drilling/sowing/ in rows	Mainly in rainfed area, some in irrigated areas with precise water control
Direct seeding in wet bed	Puddled soil	Pre-germinated seeds sown, may be aerobic or anaerobic	Various	Mostly in favourable rainfed lowlands and irrigated areas with good drainage facility
Direct seeding in standing water	Puddled soil, standing water	Dry or Pre-germinated seeds sown mostly in anaerobic condition	Broadcasting on standing water of 5-10 cm	In areas with red rice or weedy rice problem and in irrigated lowland areas with good land levelling
Aerobic wet seeding	Puddled soil	Mostly aerobic	Broadcasting on puddle soil surface; row seeding in open furrows or on flat soil surface	In irrigated areas with good drainage
Anaerobic wet seeding	Puddled soil	Mostly anaerobic with a thin layer of settling mud, row seeding in furrows and covering with soil	Broadcasting and covering	In irrigated areas with good drainage

Table 1. DSR system classification (Adapted from Joshi *et al.,* 2013)

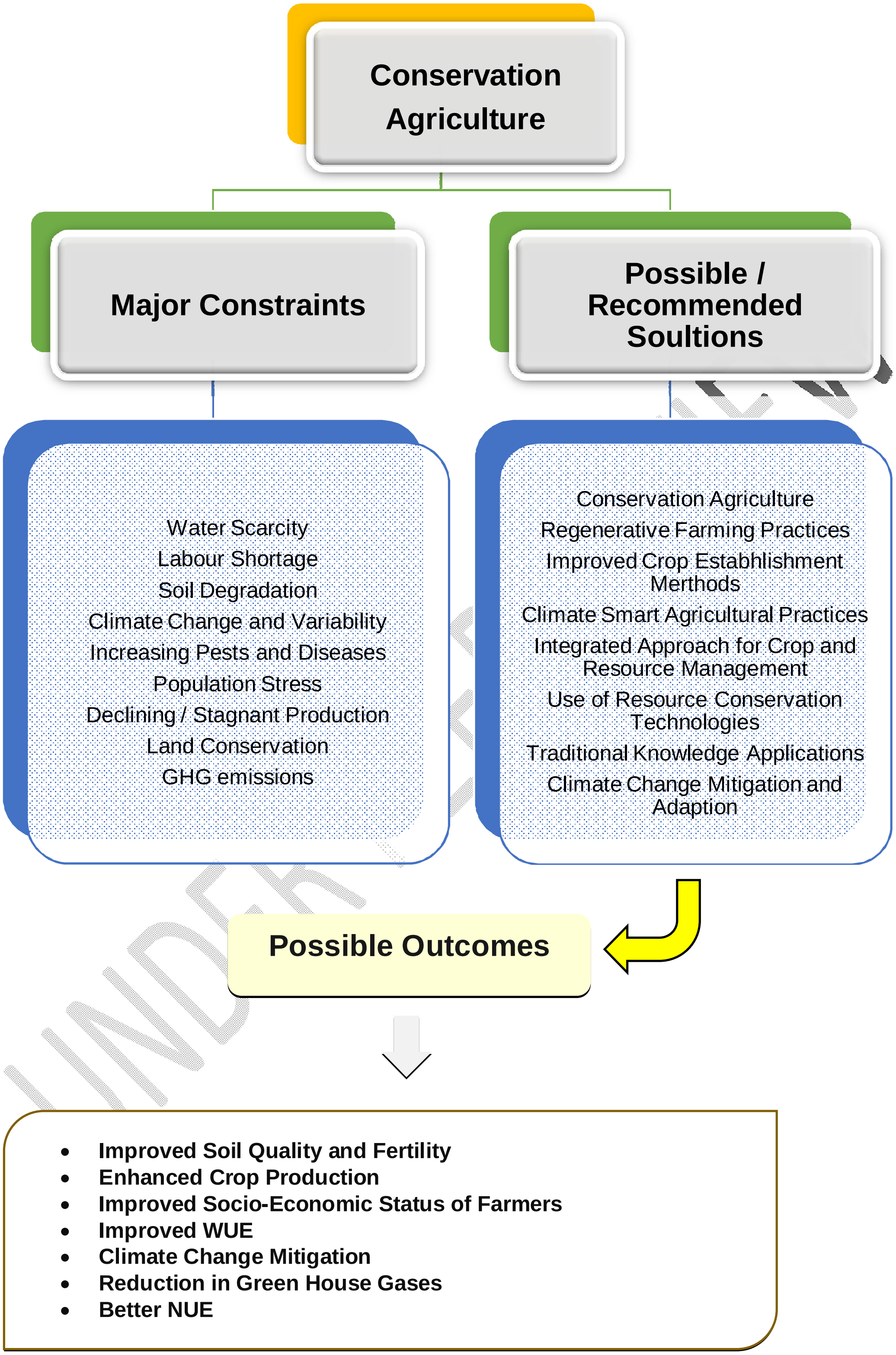

Figure 1. An illustration of the main obstacles to conventional agriculture, potential remedies, and the results of emerging agronomic practices