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Direct Seeded Rice Might Be One of the Potential Climate Smart Agricultural Technologies in Nepal

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ABSTRACT

The conventional system of puddled transplanting of rice (PTR) with intensive tillage is common practice of rice growing in Nepal. It has many negative impacts on soil, water, labor, climate change and gender equality. Therefore, an alternative production system has been explored. Direct seeded rice (DSR) has been one of the potential systems of rice production in Nepal. The results of various studies on DSR revealed that it saves labor, requires less water, less drudgery, less energy, early crop maturity, low cost of production, better soil physical conditions and less greenhouse gas emission. The grain yields in DSR are comparable with PTR. However, special attentions must be given in selection of suitable cultivars, appropriate time of sowing, optimum seed rate, proper weed and water management practices. Despite its promise, the rate of its adoption is not as expected. It might be due to some of the constraints associated it. In this paper an attempt has been made to highlight the works done in DSR within and outside of the country, its constraints and the possible solutions to scale-out it.

Keywords: Direct seeded rice, climate smart, adoption, yield

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INTRODUCTION

Rice is the major cereal crop of Nepal and its average yield was 3.47 Mt ha^{-1} (MOALD 2022) and lags in comparison to other neighboring countries Bangladesh (4.4 t ha^{-1}) and China (6.7 t ha^{-1}) albeit at par with India (3.7 t ha^{-1}), and Pakistan (3.5 t ha^{-1}). Between 1960 and 2017, the annual growth rate of rice yield in Nepal was 1.14% which is substantively less than the neighboring countries such as India (2.5%), Bangladesh (3%) and China (4.2%), and world average (4.5%) (FAOSTAT 2019). Rice contributes about 20% to Agricultural Gross Domestic Product (AGDP) and 7% to Gross Domestic Product (GDP) (MoALD 2020, CBS 2018).

Cultivation practice is one of the major production factors in rice. Puddling has been the common practice of land preparation in rice cultivation. In puddling the soil is saturated by flooding followed by plowing the supersaturated soil and again plowing or harrowing at progressively lowers water content. Transplanting is done after the puddling. Ghildyal (1978) highlighted that during puddling coarse aggregates are broken down, non-capillary pore spaces destroyed, water-holding capacity increases, hydraulic conductivity and permeability decreases, evaporation decreases and soil reduction is favored. Hence, the existing puddling and transplanting systems of rice seems not good in terms of soil quality, soil health, water use efficiency, climate change, labor demand and production cost.

Considering the above facts in rice, Direct Seeded Rice (DSR) can be an alternative to conventional PTR system. Direct seeded rice refers to the process of developing seed crops from field seeds instead of transplanting seedlings (Farooq et al 2011). Direct seeding eliminates three main basic operations, namely puddling, transplantation and the management of standing water. Direct seeding refers to either wet or dry methods, depending on the manner of crop establishment. Wet-seeding involves sowing pre-germinated seed, either broadcast or drilled, on to puddled wet soil, and then gradually flooding the land. In dry-seeding, rice is broadcast or drilled into dry soil and the seed is then covered. Direct Seeded Rice (DSR) is the technology which is water, labor and energy efficient along with eco-friendly characteristics and can be a potential alternative to CT-TPR (conventional puddled transplanted rice) (Kumar and Ladha 2011). DSR offers certain advantages viz., it saves labor, requires less water, less drudgery, early crop maturity, low production cost, better soil physical conditions for following crops and less methane emission, provides better option to be the best fit in different cropping systems (Kaur and Singh 2017). DSR utilizes less water and labor (12–35%), lowers methane emissions (10–90%), enhances soil physical properties, takes less labor and has lower production costs ($9–125 per hectare), while yet producing comparable yields (Chaudhary et al 2023). In order to produce rice sustainably and with resilience in adverse climatic conditions, direct seeded rice (DSR) methods should be applied. Therefore, an attempt was made to update the works within and outside of the country, its significance and the way forward in this paper.

FINDINGS

Despite the tremendous yield potential, the productivity of rice remains low in Terai (Karki 2013). Intensive tillage based conventional agricultural system destroy the soil's physical, chemical and biological properties thereby crop yields (Ishaq et al 2002). Weed infestation is one of the major factors that contribute to low system' productivity in the country (Karki et al 2014a). It is estimated that flooded rice fields produce about 10% of global methane emissions. In order to save water and labor and promote conservation agriculture (CA), with no/reduced tillage, it is absolutely essential to replace puddle transplanting with direct seeding. In South Asia, DSR is being practiced on terraced and sloppy lands of Bangladesh, along the coast and Western Himalayan region of India (Gupta et al 2007). The author found that after two seasons of experimentation (2010-2012) at Rampur the rice yield under DSR was at par with PTR. However, Ali et al (2014) reported the higher productivity of DSR than transplanted rice.

Table 1. DSR practices, sowing methods and ecologies

Direct seeding types	Seed bed preparation	Sowing method	Rice growing ecology
Direct seeding in dry bed	Dry seeds are sown in dry and mostly aerobic soil	Broadcasting, drilling or sowing in rows at depth of 2-3 cm.	Mainly in rain-fed area, some in irrigated areas with precise water control
Direct seeding in wet bed	Pre germinated seeds sown in puddled soil, may be aerobic or anaerobic		Mostly in favorable rainfed lowlands and irrigated areas with good drainage facility
Direct seeding in standing water	Dry or pre-germinated seeds sown mostly in anaerobic condition in standing water	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 leveling

Transplanting and direct sowing are the most common methods of crop establishment in rice. In transplanting system, rice seedlings are transplanted in the puddled field which requires huge amounts of water and higher numbers of labors for uprooting seedlings, puddling field and transplanting. Similarly, repeated puddling also adversely affects the soil physical properties by dismantling soil aggregates, reducing permeability in sub-surface layers and forming hard pans at shallow depths which make land preparation difficult and require more time and energy to achieve proper soil tilth for succeeding crops. It is well documented that the negative impacts of puddling on the soil environment, especially on beneficial microorganisms and soil aggregation (Jat et al 2014).

DSR systems are classified into (1) dry-direct seeded rice (DDSR) (Photo 1), (2) wet-direct seeded rice (photo 2) and (3) water seeded rice (Table 1). In DDSR, rice is established using different methods, including (i) broadcasting of dry seeds on un-puddled soil after zero tillage or conventional tillage, (ii) dibbled method in a well-prepared field, and (iii) drilling of seeds in rows after conventional tillage, reduced tillage using a power tiller-operated seeder, zero tillage or raised beds (Kumar and Ladha 2011). In wet direct seeded rice, usually drum seeder is used. In water seeded rice, pre-germinated seeds are broadcasted in standing water on puddled or unpuddled soil. Beside irrigated areas, water seeding is practiced in areas where early flooding occurs and water cannot be drained (Kumar and Ladha 2011).

Photo 1. Dry-DSR using tractor mounted drill

Photo 2. Wet-DSR using drum seeded

Photo 3. DSR after maize at Rampur, Chitwan

Photo 4: Seed production of rice under DSR, Khumaltar

In Nepal rice is produced mainly under rainfed lowland and upland production systems. Upland rice is popular among farmers of mid and western hills, which is direct seeded in summer season (AGD 2017). Productivity of upland rice depends on several climatic parameters (temperature, rainfall, humidity, etc.), hydrological properties, soil, pH, organic carbon, cation exchange capacity, rice varieties, and major production inputs, such as fertilizer management practices (AGD 2017). The summarized benefits of DSR technology reported by Pathak et al (2011):

- It preserves physical properties of the soil,
- It facilitates in time rice sowing and provides sufficient time for next crop,
- It saves 50% production cost compared to transplanted rice,
- Less labor (35-45) required for a hectare of rice cultivation.
- It saves 30-40% irrigation water,
- Energy consumption reduced by 27%
- Rice yield remains unaffected

By reducing the amount of time required for field preparation, DSR helps advance the planting dates of subsequent rabi crops by at least 7 to 10 days (Jat et al 2022). According to the findings, DSR technology can potentially prevent up to 70% of crops from lodging under unfavorable weather circumstances (Jat et al 2022). When compared to mechanically transplanted rice, DSR offers a yield advantage of about 10% (Jat et al 2022). In the research front, NARC and agriculture university/colleges (AFU, TU etc.) has conducted many experiments on DSR. A rice yield of up to 6 mt ha^{-1} was attained utilizing the DSR method on the Sambha Masuli-1 rice variety with moderate agronomic practices, according to a study conducted jointly by the International Rice Research Institute (IRRI) and Nepal Agricultural Research Council (NARC). When compared to traditionally transplanted rice (TPR), DSR had a benefit-cost ratio of 2.0 and a net profit of up to NPR. 62,000 ($570/ha) (Timsina et al 2023).

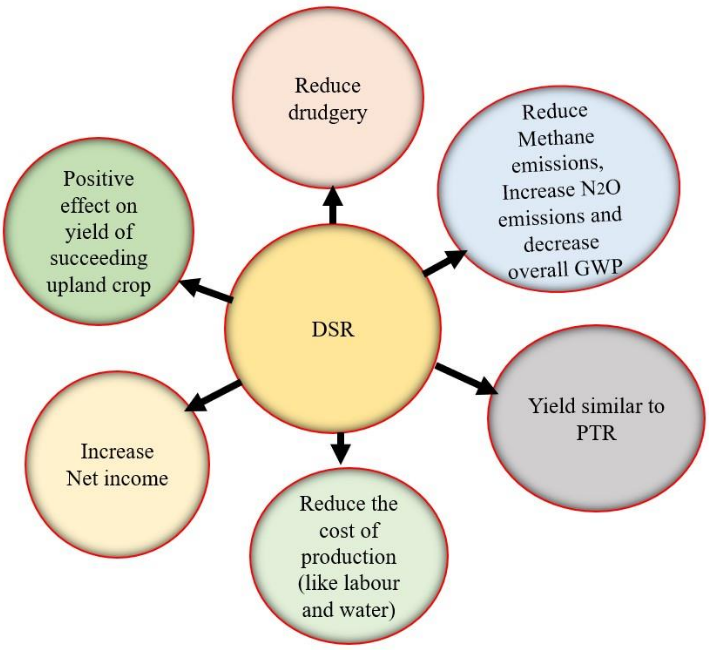

Figure 1. Benefits derived from DSR [Adapted from Kumar and Ladha (2011), Chakraborty et al. (2017)]

Variety/genotypes and time of planting for DSR:

No specific varieties are recommended for DSR; however, the performance pf drought tolerant rice genotypes perform better under DSR. For the Madesh Province, NRRP (2015) identified IR05N341, IR12A190, IR11A325 and IR11A306 genotypes were found to be suitable for DSR. In this experiment, rice yield was higher under DSR compared to transplanted rice.

During spring season (March sowing) genotypes Hardinath-1, IR92521-173-1-1-1, IR93835-73-23-1 and IR93821-41-1-2-1 produced the higher grain yield of 5.6, 5.6, 4.9 and 4.8 t ha^{-1} respectively in Eastern Terai condition (NRRP 2015).

Regarding the sowing dates, RARSN (2016) found 21st May as the best sowing date for DSR in mid-western Terai. The highest grain yield of 6600 kg ha^{-1} was recorded in seeding date of 21st May and the lowest of 3400 kg ha^{-1} in seeding date of 5th July. In the midhills, Khumal 10 variety can be directly seeded on 1st week of June.

Effect of DSR on soil moisture content

The soil moisture content (% by volume) after the fourth season of maize harvest, depicted that it was statistically significant for establishment methods during the entire crop duration (Table 2). CA had significantly higher soil moisture content across all-time series starting from 30 DAP to 130 DAP compared to ConA. The effect of weeding methods on soil moisture content was only found evident at 60, 110 and 120 DAP (Table 2).

Table 2. Soil moisture content after fourth season in rice-maize system as influenced by establishment methods, nutrient levels and weeding methods at Rampur, Chitwan, Nepal, 2012.

Treatments	Soil moisture content (SMC%)										
	Days after planting (DAS)										
	30	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**	**130**
Establishment methods											
ConA	20.1	21.0	23.8	21.9	21.4	21.7	26.9	23.6	22.8	25.6	22.8
CA (NT+Residue)	20.8	21.8	25.3	23.5	23.0	23.3	28.9	25.5	26.0	27.3	24.6
SEM (±)	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.5	0.1	0.1
LSD (0.05)	0.1	0.1	0.1	0.4	0.2	0.3	0.6	0.3	3.0	0.8	0.4
CV, %	0.3	0.3	0.6	0.9	0.2	0.3	0.4	0.4	2.2	0.9	1.5

(Source: Karki et al 2023)

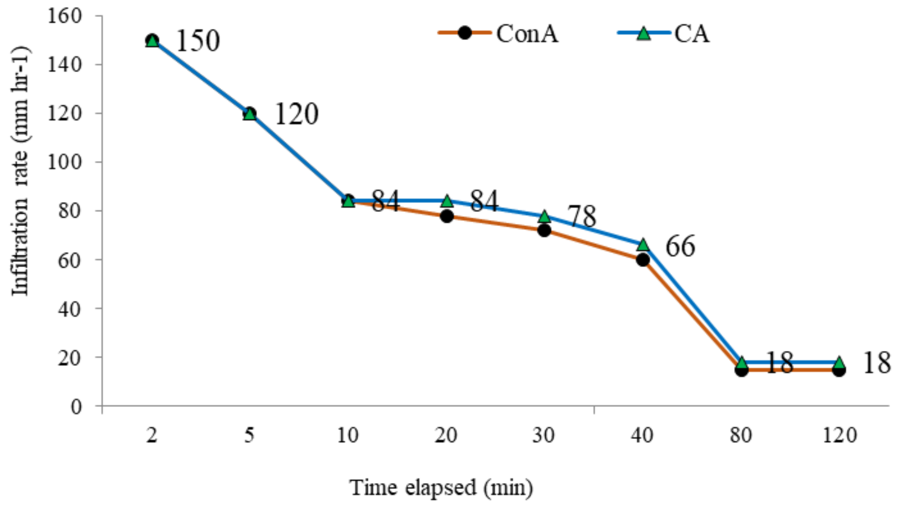

Fig 2. Infiltration rate of soil as affected by crop establishment methods, 2012 (Source: Karki et al 2023)

Infiltration rate was directly affected by crop establishment methods. Zero tillage with residue retention had higher soil water content than zero tillage with residue removal and conventional tillage with or without residue, and the effect was more It might be due to the effect of no tillage planting with rice crop's residue under CA. Soil with a higher level of organic matter (Figure 2) has a higher percentage of micro and macro-pores, which allows it to store more water than soil low in organic matter. Also, organic matter reduces the bulk density of a soil (again due to higher pore content) therefore allowing for better infiltration of rainfall and snow melt (Andrews 2006). Surface residues decreases convection, which decreases the gradient in partial pressure of water vapour between the soil and the general atmosphere. Together with lower temperature, this reduces evaporation from the soil surface and keeps soil moist for a longer period (Teasdale and Mohler 1993). This might be the reason for greater soil moisture in CA. Van Donk et al (2010) also revealed that soil covered by crop residue could hold the 90 mm more soil water in the soil profile of 1.83 m compared to the bare soil by the end of the crop season. Similarly, Verhulst et al (2011) evaluated soil water content (0–60 cm) in different tillage and residue management practices in the semi-arid areas of the Mexican highlands for a maize-wheat rotation. It was due to recharged or retention of more water during winter fallow on soil profile of zero tillage causing the difference. Use of crop residue reduced the evaporation losses by 56.5%, increased aggregate distribution and increased infiltration as well (Govaerts et al 2009).

Water productivity

The per hectare water productivity on direct seeded rice fields was 1.27 kg per m^3 whereas on puddled fields it was 0.61 kg per m^3 which means that DSR technology resulted in the enhancement of water productivity of paddy crop (Sidana et al 2022). The per hectare water productivity on direct seeded rice fields was 1.27 kg per m^3 whereas on puddled fields it was 0.61 kg per m^3 which means that DSR technology resulted in the enhancement of water productivity of paddy crop (Sidana et al 2022).

In DSR, the rice seed is placed in the soil, either with or without irrigation before sowing. This method may be more water-efficient because it doesn't call for ponding and the paddy field receives much less water before sowing. According to Deb et al (2023), a minimum water savings of 18% can be made with the DSR system in comparison to TPR.

DSR and Alternate Wetting and Drying (AWD) Method

Alternate wetting and drying technique can reduce water use by 30 percent and reduce greenhouse gas emissions by 90 percent without reducing rice yield (https://jpn.mars.com/en/news-and-stories/articles/sustainably-sourcing-rice-future). Likewise, AWD under DDSR reduced total water input by 27–29% and improved the leaf area index (LAI), tillering, yield (7–9%), and water productivity by 44 to 50% (Muhammad et al 2020).

DSR and greenhouse gas emission

Puddled transplanted rice makes up 12% global methane emissions and a staggering 1.5% total greenhouse gas emissions (Julia et al 2022). Currently, to clear fields for future crops after the use of combined harvester, farmers either burn the rice straw, which results in significant carbon dioxide emissions as well as methane, carbon monoxide, nitrogen oxides, sulfur oxides, and particulate matters, or they flood the field to encourage swift decay, which also leads to extensive methane emissions. DSR reduces methane emissions ranging from 10 to 90% (Chaudhary et al 2023).

DSR and soil organic carbon sequestration:

An experiment was conducted by the author having two establishment methods consisting of conservation agriculture (no till with residue) and conventional till (without residue) under rice-maize cropping system of National Maize Research Program, Rampur's agronomy farm during 2010 to 2016, the soil's organic matter (SOM) was analyzed after each crop harvest; however, the ANOVA was prepared only for first, second, fourth and eighth season of the experimentation. None of the tested treatments affected the SOM (%) during the first two seasons (Figure 2). SOM (%) over benchmark value of 1.13% was consistently increasing with the advancement in experimental period and was illustrated by the mean value of 1.136 in the first season to 2.06% in eighth season. In both the seasons, the SOM was statistically higher in CA than ConA and the similar results were recorded under recommended doses of nutrients (2.31%) over farmer's doses of nutrients (2.38%) (Figure 2). But weeding methods had no effect on the SOM across the seasons.

Alvear et al (2005) found higher soil microbial bacteria and N in the 0-20 cm layer under zero tillage than under conventional tillage (disk-harrowing to 20 cm) in an Ultisol from southern Chile and attributed this to the higher levels of C substrates available for microorganism growth, better soil physical conditions and higher water retention under zero tillage. Reduction in tillage intensity leads to increased soil organic matter and to accumulation of crop residue (Lal 2015) which might be reason for higher SOM on conservation agriculture than conventional agriculture as shown in above table. Verhulst et al (2009) also found highest organic matter content under zero tillage with residue retention (>20%) than other treatments. No-till management is a proven practice for increasing soil organic matter in many environments (Nunes et al 2018). Because most N in the soil is found in organic matter at a relatively constant proportion (Cleveland and Liptzin 2007), more soil organic matter almost always means more soil N.

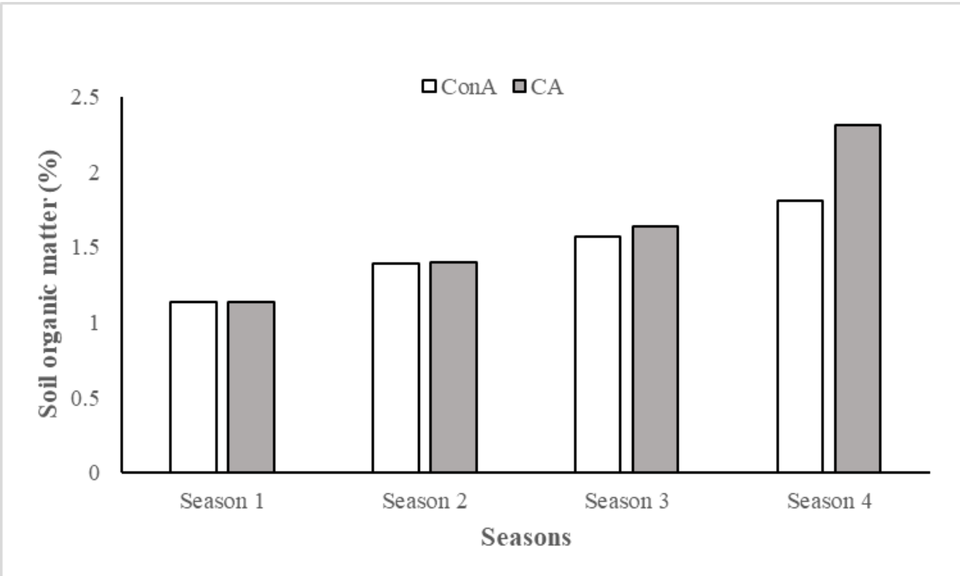

Figure 2: Soil organic matter as influenced by establishment methods at Rampur, Chitwan, Nepal, 2010-2014 (Source: Karki et al 2023)

Limitation

Weed invasion, crop lodging, and fertilizer losses are some of the DSR limitations. Rainfed culture, inadequate drainage, and delayed economic growth are the main obstacles to DSR in the South Asian region (Pandey et al 2002). Similar issues were reported in China with regard to poor crop establishment, weed infestation, lodging susceptibility, and nitrous oxide gas production. The yield has decreased in DSR as a result of continuous cropping and a lack of variety development Liu et al (2014). According to Qureshi et al (2004), DSR decreases methane emissions while increasing nitrous oxide emissions (particularly under dry-DSR). Greater nitrogen loss occurs under dry-DSR conditions with higher nitrous oxide emissions (Hou et al 2000). Although DSR have many positive impacts on soil, water, environment and economics, very less studies have been done in this regard in Nepal. The authors have limited options to illustrate the findings in assessing PTR and DSR's effects in GHG production and emission and their effects on crop from in Nepal.

The way forward

Different types of DSR practices (dry-DSR, wet-DSR and water seeding) can be adopted in Nepal for rice cultivation. These techniques have advantages over TPR due to lower inputs with comparable yield as well as quick crop establishment by reducing transplanting shock leading to an early harvesting. There must be a strong research and development program in promoting DSR in Nepal. Collaboration with the concerned international and national institutions is another option. Concerned authorities like International Rice Research Institute (IRRI), Nepal Agriculture Research Council (NARC) and National Rice Research Program (NRRP) should facilitate the research and extension programs on DSR. Basic research in generating knowledge on how DSR is climate smart is to be done by NARC. On-farm verification of the DSR technology across the terai, river basin and mid hills rice production ecologies need to be intensified jointly by NARC and provincial and local level government's extension bodies.

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AUTHORS' CONTRIBUTION

TB Karki conceptualized the topic of the paper and prepared the manuscript jointly with the co-authors namely R Neupane, RK Bhattarai, B Chaulagain, S Kaduwal, P Gyawaly, R Acharya, SK Das and J Shrestha.

CONFLICTS OF INTEREST

There is no conflict of interest regarding this manuscript.

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