



## Direct Seeded Rice and its Prospects in Nepal: A Review

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### ARTICLE INFO

Review Article

Received : 18/04/2021

Accepted : 05/05/2021

Keywords:

Advantages

Constraints

Direct Seeded Rice (DSR)

Nepal

Prospects

### ABSTRACT

Direct Seeded Rice (DSR) is an alternative cultivation technique to the conventional Transplanted Rice (TPR). In this method, seeds are directly sown to the field without the necessity of nursery raising and transplanting. DSR can generally be divided into dry-DSR (sowing dry seeds in dry soil), wet-DSR (sowing pre-germinated seeds in moist soil) and water-seeding (sowing dry or pre-germinated seeds in standing water). This helps in saving water alongside the labour and results in early harvest due to quick crop establishment. DSR is proved to be sustainable and eco-friendly since it emits less methane than in TPR. However, there are few constraints associated with DSR such as weed infestation, crop lodging and nutrient loss. If these major issues are fixed, DSR can result in greater economic returns as compared to TPR. In absence of puddling, the soil structure can be maintained which leads to greater yields of succeeding crops. This technique has been successfully practiced in many countries like Srilanka, Malaysia and USA. In developing nations like Nepal, irrigation and labour constraints can be tackled by adopting direct-seeding for rice cultivation.

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## Introduction

### Rice

Rice belongs to the family Gramineae. *Oryza sativa* L. is the most widely cultivated species of rice among 20 genera of *Oryza* (Fageria, 2007). Being staple food for more than half of the world, it is important to maintain the stable production of rice to feed the constantly growing human population (Roychowdhury et al., 2012). The total production of rice in the world is 782,000,147 metric tons (FAOSTAT, 2018). It provides 30–75% of the total calories to more than 3 billion Asians (Kumar and Ladha, 2011a). Rice is grown in at least 114 countries globally and more than 50 countries have an annual production of over 0.1 million tons (Mt) (Pathak et al., 2011).

### Cultivation Techniques

The conventional rice production system involves the rising of nursery seedlings followed by transplanting in puddled flooded soil. This process requires a lot of water, energy and labour resources. So, farmers around the globe have shifted their interest towards alternate cultivation practices (Nawaz et al., 2019). In order to cope with increasing labour costs, two significant changes have been

made historically in crop establishment methods. In temperate Asian countries such as Japan, Korea, and Taiwan, farm labour shortages have led to a transition from manual to mechanical transplantation whereas in tropical countries such as Malaysia and Thailand the trend has shifted to direct seeding (Pandey and Velasco, 2002).

### Direct Seeded Rice (DSR)

Direct seeding involves the establishment of rice crops from seeds sown in the field instead of transplanting seedlings from the nursery (Farooq et al., 2011). The fields at least need to have sufficient moisture in DSR for successful germination unlike being flooded in TPR (Cabangon et al., 2002). In general, three principal methods of DSR are in practice viz. dry seeding (sowing dry seeds into dry soil), wet seeding (sowing re-germinated seeds on wet puddled soils) and water seeding (seeds are sown into standing water) (Farooq et al., 2011). The role of DSR has been realized especially in the low-income Asian countries with high population growth rates where the rice demand is estimated to increase by 30-50% over the next 30 years (Mortimer et al., 2008).

## History

Rice cultivation began when the hunting, fishing and food-gathering inhabitants near the rivers and along the foothills, dropped seeds into low-lying fields. Modern rice evolved as a result of persistent human and artificial selection (Chang, 1976). The domesticated species *Oryza sativa* i.e. Asian rice evolved 9,000 years ago and spread subsequently from its centre of origin (India and China) to the rest of the world (Purugganan, 2010). Despite several types of research and studies, the beginning of rice domestication still remains unclear (Z. Zhao, 2010). *Oryza sativa*, the most important commercial species of rice, is differentiated into three subspecies- *indica*, *japonica* and *javanica* based on their commercial production zones (Gadal et al., 2019). Compared to its culture in Asia, rice in southern Europe, the United States, and Australia have a relatively short history. Rice was introduced into Italy during the fourteenth and fifteenth centuries. In the United States, rice was first produced commercially in the middle of the eighteenth century and in Australia, rice was first produced in the twentieth century (Hill et al., 1991).

Historical accounts of rice cultivation in Asia indicate that, during its early period of domestication, the rice used to be dry sown in a mixture with other crops that were established under the shifting cultivation system (Pandey and Velasco, 2002). In the early twentieth century, Mekong Delta (Vietnam) farmers used direct seeding for their floating rice (Can and Xuan, 2002). By the 1950s, transplanting had become the dominant

method of crop establishment in most of Asia. Dry seeding was practiced only in those areas where low population density or severe climatic/hydrological constraints prevented intensification of rice systems (Pandey and Velasco, 2002). Since the early 1980s, direct seeding of rice has quickly replaced transplanting because of increased cropping intensification, higher costs for transplanting, lack of farm labour, and the availability of short-duration rice varieties (Can and Xuan, 2002). Malaysia, Thailand, Vietnam, China adopted DSR in the second half of the twentieth century (Kumar and Ladha, 2011a)

### Types of DSR

There are two methods of direct seeding rice, dry and wet seeding, based on the physical condition of the seed and seed environment. Wet seeding is further divided into aerobic wet seeding, anaerobic wet seeding, and water seeding, based on the oxygen level in the vicinity of germinating seeds. Rice seeds are broadcasted or drilled in rows on dry, moist, or puddled soil, whereas only aerial or mechanical broadcasting is done for water seeding (Balasubramanian and Hill, 2002). The presence of longitudinal aerenchyma channels facilitates oxygen diffusion from the shoots to the root tips, allowing rice plants to grow well in flooded paddy fields (Yamauchi et al., 2013).

Table 1. Classification of Direct-seeded Rice systems

Direct seeding method	Seed bed condition	Seed type	Land preparation Procedure	Seeding Pattern	Water regime (0-14 days after sowing)	Suitable area for practice
Dry-seeded rice	Dry soil (unsaturated or moist), aerobic	Dry seed	Dry, reduced or zero tillage; Ploughing and harrowing with sufficient moisture	Broadcasting, Drilling (mechanized seed drill) or Sowing in rows (mechanical or manual)	No standing water until rice has reached 3-leafed stage)	Rainfed highland (Bari) or dry land with precise water control
Wet-seeded rice	Puddled soil, aerobic/ anaerobic	Pre-germinated seed	Dry or wet tillage; ploughed, flooded, puddled and levelled	Broadcasting (by hand or mechanized blower), Row seeding (drum seeder)	Saturated soil initially (0-0.3 cm surface water)	Rainfed lowland and irrigated areas with good drainage facilities
Water-seeded rice	Puddled or unpuddled soil, Standing water (3-5 cm), mostly anaerobic	Dry or pre-germinated	Dry or wet tillage; ploughed, flooded, (puddled) and levelled	Broadcasting (manual or motorized blower)	Standing water (5-10 cm)	Irrigated lowland with proper land levelling and in areas with red / weedy rice problem

Modified from: (Balasubramanian and Hill, 2002; Joshi et al., 2013; Rao et al., 2007)

### Varieties of DSR

DSR requires specially bred cultivars with the effective root system (Pantuwan et al., 2002), good mechanical strength in the coleoptiles, early seedling vigour for weed competitiveness and efficient root system (D. L. Zhao et al., 2006). Greater carbohydrate reserves in larger seeds support the adequate seedling growth (Namuco et al.,

2009). African rice is cultivated less intensively outside Africa. However, global interest has arisen lately because of its tolerance to abiotic stresses (Meyer et al., 2016). Genetic parameters for DSR varieties include grain yield per hill, spikelets per panicle, plant height, flag leaf width, flag leaf length, spikelets and no. of tillers per hill

(Ragvendra et al., 2011). Tyagi and Chander (2020) have reported timely sowing of succeeding crops by 7-10 days using early maturing varieties (Tyagi and Chander, 2020). According to Dawadi and Chaudhary (2013), *Hardinath-1*

varieties produced significantly higher grain yield, net return and higher B: C ratio in DSR. In addition to these, greater grain and straw yields were observed in the crop shown on June 13 (Dawadi and Chaudhary, 2013a).

Table 2. Varietal response to DSR and TPR

S.N	Countries	Varieties for DSR	Yield (tons/ha)TPR	Yield (tons/ha) DSR
1	Nepal	Sonamansuli, Hardinath-1, Sukhaa, Chaite, Radha-1, Ram-dhan, Sabitri, Lokhnath-505	3.71	3.6
2	India	Mahsuri-1, KrantiPusa-2511, Pusabasmati, Pant-dhan	6.8	6.6
3	China	Lyhan-1, Huanghuazhan, Yangliang, Jiangsu	8.1	10.4
4	Bangladesh	BRR1 Dhan-39, BRR1 Dhan-44, Zata	NA*	NA*
5	Pakistan	KS-282	3.42	3.6
6	Philippines	IR64, IR10, IR42, C2, C4, UPL, RI-7	5.94	6.07

Modified from: (Farooq et al., 2011), \*NA: Not Available, Inbreds (*Hardinath-1*, *Tarahara-1*, *Radha-4*, *Sukha-1*, *Sukha-2*, *Sukha-3*, *Ramdhan*, *Sabitri*), Hybrids (*Gorakhnath*, *Arize 6444*, *Bioseed 786*, *RH 245*, *Loknath-505*, *Raja*) are recommended DSR varieties for terai and inner-terai of Nepal. Similarly, *Khumal-4*, *Khumal-8*, *Khumal-10* are recommended for mid-hills whereas *Chhomorong* is recommended for the high hills of Nepal. (Devkota et al., 1999; M. L. Shah & Bhurer, 2005)

### Present Status of DSR

The largest producer of rice in the world is China followed by India, Indonesia, Bangladesh and Vietnam. The production share of Asia is the largest i.e. 90.2%, followed by the America (5%) and Africa (4.2%) (FAOSTAT, 2018). The annual rice production of Nepal is 5,151,925 tons, whereas that of China is 214,078,796 tons and that of India is 172,580,000 tons. (FAOSTAT, 2018).

Direct seeded rice (wet and direct seeding) is about 95% of the total rice grown in Sri Lanka (Weerakoon et al., 2011a). In Malaysia, DSR accounted for more than 90% of the total rice area planted by 2000 (Azmi et al., 2005). Rice is irrigated and mainly directly seeded in the Mekong River Delta of Vietnam. Wet seeding is more common however dry seeding, water seeding; zero tillage is also in practice (Azmi et al., 2005). Introduction of new herbicides, short-duration varieties (95 - 105 days), early establishment as well as harvesting of dry- DSR in August led to the cultivation of another rainfed rice and even the third crop during December to February in the Mekong River Delta region of Vietnam (Mortimer et al., 2008; My, 1995; Pandey and Velasco, 2002).

Farmers in the developed parts like the US, Europe and Australia practice direct seeding of rice with high mechanization, development of short duration, early maturing cultivars and proper nutrient management techniques including integrated weed management (Azmi et al., 2005). Rice cultivation in the US can be classified into water seeding (33%) and dry DSR (67%). It is mostly mechanized with the precise use of laser technology for proper land levelling, aircraft for seeding and pest control along with self-propelled combines for harvesting (Gathala, 2013).

DSR is likely to expand in Southeast Asia having low population density, higher wage rate and mechanization except in traditionally transplanted areas (Pandey and Velasco, 2002; S. P. Singh et al., 2008). DSR is being popular in Taihu Lake Basin (TLB) of China with more than 50% of the farmland under rice cultivation (Gao et al., 2006). The direct-seeded rice was found as a better alternative to TPR in Central China due to its less demand of labour, higher output to input ratio, higher NUE,

improved uptake of nitrogen and identical grain yield (Liu et al., 2014).

In the northwestern Indo-Gangetic plains where rice-wheat cultivation is dominant, zero tillage DSR provided higher yield, less irrigation water, increased net economic returns and reduction in the production cost in comparison to puddled transplanted rice. Further, double zero tillage can be an effective method of field preparation in rice-wheat-growing regions (Gathala, 2013). DSR (wet and direct seeding) is about 95% of the total rice grown in Sri Lanka. The average yield of DSR in dry and wet zones is 5 tons per hectare and 3.3 tons per hectare respectively (Weerakoon et al., 2011b). In Bangladesh, DSR is mainly practised during pre-monsoon in the rainfed upland and also during monsoon in rainfed rice (Shelley et al., 2016). According to a study conducted in the Philippines, DSR was generally adopted in small, medium-sized farms rather than big farms due to economic incentives. DSR was mainly practised in the high elevated areas with water shortages alongside the areas with adequate irrigation systems (Satter and Bhuiyan, 1993).

M. Devkota et al. (2019) reported comparable yields and lower production cost (by \$ 160 ha<sup>-1</sup> in DSR as compared to TPR) in western Terai of Nepal. In addition to this, water productivity was found to be greater by 4-18%. This led to a net profit of \$ 122–232 ha<sup>-1</sup>.

### Advantages of DSR

The advantages of DSR over TPR include low water requirement during land preparation, early crop establishment and efficient use of early-season rainfall (Cabangon et al., 2002; My, 1995). Adoption of DSR resulted in less labour use, reduced variable and total cost per cultivated area which led to greater net returns (Isvilanonda, 2002). Transplanting is done mostly by the hired labour whereas the activities of DSR (soaking, transporting, broadcasting of seeds and replacing of seedlings) are done mostly by family labour (Ho and Romli, 2002). Dry seeding has several advantages over wet seedings, such as good seedling stand, lodging resistance, and less incidence of bird and fungi damage (Lee et al.,

2002a). As Direct seeding needs less tillage and no puddling, soil structure is maintained and makes soil aerobic. The absence of transplanting shock in DSR results in early maturity (7-10 days) which facilitates timely harvest and sowing of subsequent crops (Parthasarathi et al., 2012). Tripathi and his colleagues reported 13%, 41%, and 12% less usage of human labour, machine labour, and irrigation water respectively for DSR as compared to TPR (Tripathi et al., 2014). Shorter land preparation periods for wet seeded rice resulted in 19% less water consumption and 3-17% higher yield (Tabbal et al., 2002).

Adoption of DSR saves about 40% of the labour required for nursery raising, uprooting and transplanting of seedlings (Pandey and Velasco, 2002) and 60% of diesel energy associated with field preparation and irrigation (Pathak et al., 2011). In north-west India, seepage and percolation loss amounted to 43% and 56% of total water input for Dry DSR and traditional rice cultivation respectively. Around 35-40% of water-saving was observed for dry DSR (Bhushan et al., 2007). Lee et al. (2002) reported a 30% lower labour requirement and 20% lower production cost in case of dry seeding than that for machine transplanted rice (Lee et al., 2002a). Singh et al. (2008) reported a profit of Rs 13,350 per ha for dry-seeded rice and Rs 11,592 per ha for wet-seeded rice as compared to Rs 10,343 per ha for transplanted rice (S. P. Singh et al., 2008). A national survey in China showed that on average farmers received \$103 per ha more with seedling broadcasting than with transplanting (Sheng-xiang, 2002).

### Constraints and their management in DSR

The major constraints for DSR in the South Asian region include rainfed culture, poor drainage and slow economic growth (Pandey, 2002). Likewise, in China, poor crop establishment, weed infestation, lodging susceptibility and nitrous oxide gas emission have posed serious trouble. Continuous cropping and lack of variety development have led to yield decline in DSR. (Liu et al., 2014). DSR reduces the emission of CH<sub>4</sub> however increases the emission of N<sub>2</sub>O (especially under dry-DSR) (Qureshi et al., 2004). Higher N<sub>2</sub>O emission under zero tillage dry-DSR results in greater nitrogen loss (Hou et al., 2000).

#### Weed Management

Weed is one of the major constraints for the proper adoption of DSR. The average yield of rice from direct seeding was 3.3 t/ha whereas that from transplanting was 3.7 t/ha. The reduction in average yield for DSR was 10% as compared to TPR due to weed infestation (Qureshi et al., 2004). Weedy rice is a great threat to dry DSR because of its higher N use efficiency for biomass production as compared to cultivated rice (Liu et al., 2014). About 1800 species of weeds are reported in rice worldwide of which 50 are prominent in DSR. The major weeds of Direct Seeded Rice are *Echinochloa spp.*, *Ischaemum rugosum*, *Cyperus difformis*, and *Fimbristylis miliacea* (Rao et al., 2007).

Combined efforts are necessary for effective weed management. Preparation of improved seedbed and tillage, use of weed resistance varieties and quality seeds, proper sowing time and narrow row spacing check the growth. In

addition, use of crop residues as mulch, maintenance of uniform plant population, water depth and timing produce better results in DSR. Manual/ mechanical weeding alongside herbicide combination and rotation are recommended for optimum yield (Chauhan, 2012).

Comparable yield to weed-free condition is obtained when weeding is done for the first 60-75 days only or after 15 days of sowing. When two weedings are available, the best yield is obtained when weeding is done at 15-30 DAS and 45-60 DAS (G. Singh and Singh, 2008).

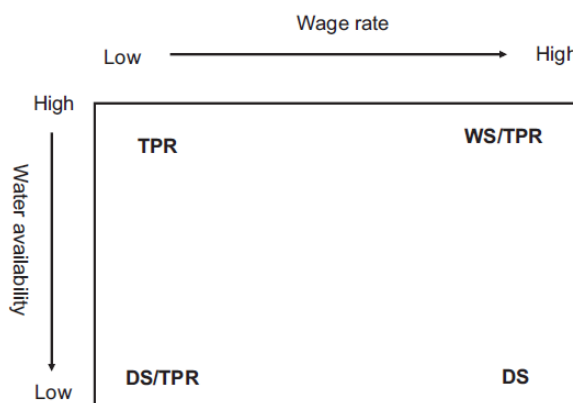


Figure 1. Factors affecting the choice of rice establishment methods.

Note: TPR = transplanting, WS = wet seeding, DS = dry seeding, Adapted from: (Farooq et al., 2011; Pandey and Velasco, 2002)

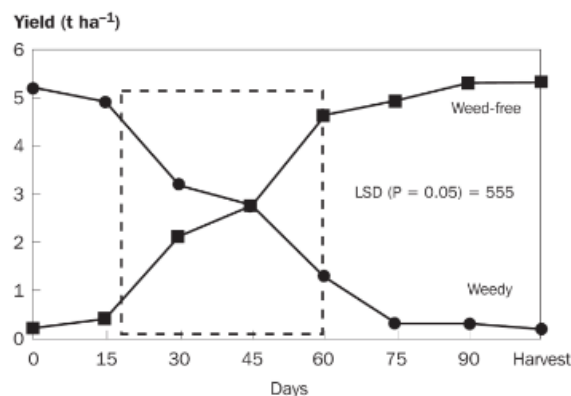


Figure 2. Critical duration of the weed-crop competition in dry-DSR

Adapted from: G. Singh and Singh (2008)

Stale seedbed preparation (7-10 days earlier) involves the stimulation of weed germination and emergence, facilitated by irrigated or rainwater. This is followed by their destruction using herbicides (paraquat or glyphosate) or shallow cultivation (G. Singh and Singh, 2008).

Mulching increases the net returns and B: C ratio in DSR as compared to non-mulch cultivation (G. S. Yadav et al., 2020). Gaire et al. (2013) reported increased productivity and reduced production cost with the use of Brown Manuring (*Sesbania* and *Crotolaria*) within 30 DAS in Chitwan and similar conditions. *Eupatorium* mulch one day after sowing showed promising results (3.5 t/ha) as compared to *Sesamum* Brown Manuring (2.97 t/ha), wheat straw mulch (2.83 t/ha) and controlled cultivation (1.77 t/ha). The B: C ratio of *Eupatorium* mulch for weed control was similar to herbicide application (2.4) (Gaire et al., 2013).

Devsinghe et al. (2011) reported effective weed control using rice straw as mulch for Wet DSR but not in Dry-DSR (Devasinghe et al., 2011). In several countries of Asia, Africa and Latin America, hand weeding is practised partially or extensively (Rao et al., 2007). Conservational tillage which utilizes crop residue as mulch with improved crop and resource management practices enhanced the production and yield (Kumar et al., 2013).

The success of DSR cultivation can be attributed to the development and accessibility of modern herbicides. For dry- DSR, the best time for herbicide application is one just before the emergence and another within one week of permanent flooding (Kim et al., 1999).

Subbaiah (2008) suggested effective combinations of herbicides based on the research for weed control. In

general, Butachlor and Safener were effective against grassy weeds whereas Pretilachlor and Safener were effective against grasses and sedges. Pyrazosulfuron-ethyl at low doses was effective against sedges and broadleaf weeds whereas Almix with surfactant was effective against broadleaf weeds.

Herbicide resistance is a great challenge associated with the repeated application of certain chemicals due to evolutionary responses (G. Singh and Singh, 2008). An integrated weed management system would be an effective, economical and eco-friendly approach for controlling weed in rice. However, a detailed study on the biology and ecology of weeds is needed for devising successful weed control measures (Yaduraju and Mishra, 2008).

Table 3. Herbicides and their application time and process

Herbicide	Active component	Time of application	Target weeds	Dose (Kg a.i ha <sup>-1</sup> )	Mode of action	Type
Paraquat	Paraquat	1-2 DBS	All types of weeds	0.5	Photosystem-I electron divider	Pre-emergence
Pendimethalin	Pendimethalin (34% w/w)	1-2 DAS	Grasses broad leaves	1.0	Microtubule assembly inhibitor	Pre-emergence
Pretilachlor	Pretilachlor (30% w/v) EC	1-2 DAS	All types of weeds	1.5	Inhibitor of long chain fatty acid synthesis	Pre-emergence
Glyphosate	Glyphosate	7-15DBS	All types of weeds	1.2-1.6	EPSP synthase inhibitor	Pre-emergence
Ethoxysulfuron	Ethoxysulfuron	10-15 DAS	Sedges, broad leaves	1.5	ALS inhibitor	Post-emergence
2,4-D	2,4-D	20-25 DAS	Sedges, broad leaves	0.5	Synthetic auxin	Post-emergence

Note: DAS- Days after sowing, DBS- Days before sowing, a.i.- active ingredient, EPSP= 5-enolpyruvylshikimate-3-phosphate, ALS= Acetolactate Synthase, Modified from: Pathak et al. (2011); Kumar and Ladha (2011a)

### Lodging Management

In wet and water seeding done at the surface level, the lodging problem is prominent at maturity. (Balasubramanian and Hill, 2002). The main lodging-inducing factors in broadcasted rice are the shallow root distribution and shallow depth of buried culm base (Lee et al., 2002a). According to Lee et al (2002), high amounts of N application also increases field lodging (Lee et al., 2002b). Lodging results in a sizable reduction in grain yield due to decreased photosynthesis by self-shading and hampers grain quality (Liu et al., 2014). It can reduce the yield of rice by 1 t ha<sup>-1</sup> (Nawaz et al., 2019). Mechanical, as well as manual harvesting of a lodged crop, is extremely cumbersome (Liu et al., 2014).

Proper irrigation management reduces the incidence of lodging. Once the seedling stand is established, the rice crop needs to be irrigated at the third-leaf stage (25-30 DAS) requiring two or three drainages to increase lodging resistance (Lee et al., 2002b). High root lodging tolerant varieties were characterized by thicker root diameter (1mm), higher amount of root weight and vertical rooting distribution into the soil layer (Kim et al., 1993). Several types of research at the gene level have been conducted to develop the lodging resistance cultivars in rice. Yadav et al (2017) have mapped 12 QTLs (Quantitative Trait Loci) associated with lodging resistance traits viz. culm length, diameter and strength (S. Yadav et al., 2017). Hirano et al

(2014) identified 9 rice mutant lines possessing improved culm strength. These mutant lines might be useful in the development of lodging resistance variety for DSR (Hirano et al., 2014). Foliar application of growth retardants like Paclobutrazol (50 or 100 ppm) retards internode, culm length and increases the culm diameter. This results in greater bending resistance and maintains optimum yield (Rani Sinniah et al., 2012).

### Nutrient Management

The recommended level of Nitrogen in dry-DSR is 150-180 Kg per ha which is 40-70 Kg higher than that for TPR and wet-DSR. Phosphate and potassium are applied at the same rate for TPR and Wet-DSR i.e. 70 and 80 Kg ha<sup>-1</sup> respectively (Lee et al., 2002b). Split application of fertilizers enhances the efficiency and improves the germination percentage alongside the crop establishment. One-third of Nitrogen should be applied as basal dose followed by two equal splits at active tillering and panicle initiation (Kamboj et al., 2012). The use of rock phosphate is reported to be a cheaper source of Phosphorus for DSR especially when legume is included in the system (Bhattacharyya et al., 2002).

The yield of TPR was found to be lower than that of DSR without the application of Nitrogen. Manipulating the fertilizer management practices increases Nitrogen Use Efficiency (NUE) and grain yield in DSR. (Pandey, 2002).

However, the NUE is less than 40% of applied N in flooded rice. (Craswell and De Datta, 1980). Denitrification, volatilization, and leaching losses are greater in dry-DSR than in TPR (Davidson, 1991). Leaf colour chart (LCC) can be used for Nitrogen management in which N is applied when the leaf colour falls below the critical limit (Kamboj et al., 2012).

The improper application of N fertilizer in DSR results in lower availability of Nitrogen, Phosphorus and micronutrients such as Zn, Fe, Mn and S (Gao et al., 2006; Ponnamperna, 1972). The principal factors governing the nutrient dynamics in DSR are land preparation and water management. (Farooq et al., 2011). Fe availability in the soil increases slightly with the prolonged submerged condition. (Pandey, 2002). However, Fe deficiency is greater during early growth periods in DSR due to poor water management. It can be corrected with foliar application of FeSO<sub>4</sub> (2-3%). (Subbaiah, 2008). Excessive uptake of Fe<sup>2+</sup> results in bronzing of rice leaves which leads to substantial yield loss (Becker and Asch, 2005). A greater concentration of Fe<sup>2+</sup> and Mn<sup>2+</sup> in soil solution has antagonistic effects on Zn absorption (Giordano et al., 1974).

Integrated Nutrient Management (INM) technique involving judicious application of NPK at 90:45:45 kg ha<sup>-1</sup> and FYM at 5 t ha<sup>-1</sup> is reported to be efficient for DSR. (Dawadi and Chaudhary, 2013b).

#### **Disease and Pest Management**

The tendency of the outbreak of diseases and pests is more in Wet-DSR than in TPR (Pongprasert, 1995). According to Tomar (2002) in rainfed lowlands, higher temperature and humidity facilitates the buildup of pest populations. Balasubramanian and Hill (2002) reported higher pest and disease incidence in DSR due to dense canopy and less ventilation around plants (especially in broadcast-sown rice with a high seed rate.). The major insect pests in DSR are brown planthopper [*Nilaparvata lugens*], rice thrips [*Stenchaetothrips biformis*], green leafhopper [*Nephotettix virescens*], leafhopper [*Cnaphalocrocis medinalis*] and gall midge [*Orseolia oryzae*] (Pongprasert, 1995). Ants, yellow stem borer and hispa also cause significant damage in rice (Tomar, 2002). Other insect pests that attack emerging rice seedlings are the golden apple snail (*Pomacea canaliculata*) and rats. Protecting young seedlings against these pests is more difficult in W-DSR than in TPR (Balasubramanian and Hill, 2002). Root-knot nematodes have been observed when switching from flooded to water conservation rice production systems like dry DSR (Farooq et al., 2011).

High diseases susceptibility was observed when the rate of seedling exceeded 200 per sq m. Similarly, a greater incidence of diseases was observed with a high amount of N application. ((Lee et al., 2002a). The major diseases in DSR are rice blast (*Pyricularia grisea*), sheath blight (*Rhizoctonia solani*), sheath rot (*Sarocladium oryzae*), and dirty panicle (*Alternaria padwickii*, *Curvularia lunata*, *Fusarium moniliforme*, *Bipolaris oryzae*) ragged stunt virus (Vector-*Nilaparvata lugens*), and yellow-orange leaf virus (Vector-*Nephotettix virescens*) (Pongprasert, 1995). The severity of rice blast increases under water limited conditions (Farooq et al., 2011). According to Wada (2002), high plant density resulting in high humidity in

broadcast fields accelerates the occurrence of diseases such as rice sheath blight. In DSR, different species of *Pseudomonas* like *P. fluorescens*, *P. aeruginosa* and species of *Bacillus* like *B. subtilis*, *B. pumilus* are effective biocontrol agents against diseases like Rice blast, Brown spot, Bacterial blight and Sheath blight (Vasudevan et al., 2002).

Only selective insecticides (such as buprofezin for planthopper) should be used against specific insects. This helps to preserve the natural enemies of insects (Wada, 2002). Adoption of the IPM strategy by combining resistant varieties, predator management, cultural practices, and/or the judicious application of pesticides will help control most insects (Balasubramanian and Hill, 2002). Whereas, IDM (Integrated Disease Management) is a multidisciplinary approach that seems promising to manage diseases effectively by integration of cultural, physical, biological and chemical strategies (Kumar et al., 2013).

#### **Water Management in DSR**

Precise water management is very important in dry drilled seeded rice, especially during the crop emergence phase (Kumar and Ladha, 2011a). Uniform spread of water in dry-DSR reduces the problem of submergence as well as drainage (Lantican et al., 1999; Tuong et al., 1994). Precise land levelling saves up to 25% of irrigation water (Rickman, 2002). (Kumar and Ladha, 2011a) recommended sowing of plants 10-15 days before the onset of monsoon. The proper time of sowing enhances the water use efficiency by 40-50% and productivity by 30%. Bund management maintains water depth and prevents water loss through seepage and leakage (Lantican et al., 1999; Tuong et al., 1994).

A flush of irrigation is necessary after sowing when there is no sign of rainfall. The field should be saturated with water at the three-leaf stage (Bouman, 2007). This helps in adequate germination, effective seedling establishment and plant growth (Kumar and Ladha, 2011b). In order to avoid water stress during flowering, the field needs to be flooded one week earlier (Bouman, 2007). The alternate wetting and drying (AWD) method of irrigation involves flooding the fields to the shallow depth of 5 cm and re-irrigating after the disappearance of water. The interval of AWD irrigation is more in Dry-DSR than in CT-TPR due to less cracking in the former. However, insufficient knowledge regarding the effect of AWD and poor irrigation facilities are the major constraints associated with the adoption of this method (Humphreys et al., 2010). Residue mulching is effective in dry-DSR, especially prior to monsoon when evapotranspiration loss is very high and plants are small (Jalota and Arora, 2002). The irrigation water requirement can be lowered by using short to medium duration cultivars that can sustain in limited water (Humphreys et al., 2010). Short episodes of drought during the flower exposure decreases panicle water potential and starch content required for pollen viability resulting in another dehiscence. This in turn produces large sterile panicles. Irrigation management during critical stages and foliar spray of Boron during flowering decreases the panicle sterility in DSR (Rehman et al., 2014).

### Miscellaneous

Priming seeds with water before direct seeding promotes uniform and vigorous germination and faster seed emergence (1-3 days) (Harris et al., 2002). Similarly, priming the seeds with 14% KCl solution and saturated CaHPO<sub>4</sub>, increases established plant density, final tiller number and grain yield in very dry soil. However, under saturated soil conditions, seed priming with the same solution decreases the plant density and grain yield. Seed priming reduces the seeding rate in drought-prone areas (Du and Tuong, 2002).

### Prospects of DSR in Nepal

Increased labour costs, scarcity of water and availability of herbicides have shifted the attention from TPR to DSR in recent years (Yaduraju and Mishra, 2008). Labour and water shortages during transplanting led to delay in cultivation and reduce rice yield in less mechanized countries. One of the main reasons for introducing DSR is to reduce the risk of establishment failure due to water shortage in the rice field at an appropriate transplanting time (Fukai, 2002). Out of 2.04 million ha cultivable land in Nepal, around 1.43 million ha land has surface and groundwater irrigation facilities. In rural areas, over 75% of irrigated land is occupied by groundwater. (T. Shah et al., 2006). Water conservation is essential to achieve yield stability and optimization in rice

production (McDonald et al., 2006). Late arrival of monsoon rain in reduced tillage condition decreases the crop establishment and delays the maturity of transplanted seedlings (De Datta and Nantasomsaran, 1991). The shallow groundwater and surface flow elements associated with the monsoon rain creates the rice-growing conditions in Nepal. When rainfall is low, drought stress is the primary growth constraint for rice cultivation (Hobbs et al., 1996). DSR followed by Zero Tillage Wheat (ZTW) produced satisfactory yield, reduced cost of production and irrigation in western Terai of Nepal. In addition, it assisted in timely sowing and mitigating the risk of climate change (M. Devkota et al., 2019). Over 4 million labour approvals have been issued by the Department of Foreign Employment (Nepal) from 2008/09 to 2018/19 (Nepal Migration Profile, 2019). Migration changes the structure of labour markets which reduces the supply of agrarian labour (Sunamand McCarthy, 2016). It leads to deactivation (migrant households engage less in farming for their livelihood) and repeasantization (landless and poor non-migrant households have more access to the land left by migrants). This results in the availability of land among non-migrants, however, creates labour shortages for farming (Van der Ploeg, 2009; Vandergeest, 2012). In Nepal, around 20% of the returnee migrant workers are employed in the Agriculture sector (Migration report, 2020). These figures reflect the prospect of alternative technique like DSR for rice cultivation in developing countries like Nepal.

Table 4. Description of Different Growth stages of rice

Growth stage	DAS	Description	DSR management practice
Germination	5	Coleoptile tip becomes visible	Pre-emergence herbicide application, Irrigation
Tillering initiation	19	First tiller is visible from the main shoot	Mechanical or chemical weed management
Active tillering	45	Maximum tillering per unit time occurs	Urea split-dose application
Panicle primordia initiation	61	Panicle initiation starts	Irrigation
Booting	85	The panicle is within the uppermost leaf sheath	-
Flowering	95	Flowers become visible on the panicle	Irrigation
Physiological maturity	120	Grains become ripened	Panicles become ready to harvest

Note: DAS- Days after sowing, Modified from: Fageria (2007)

### Conclusion

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 harvest. Irregular monsoon rain and lack of adequate irrigation facilities in Nepal can be managed with the adoption of DSR. Labour shortages due to foreign employment have created troubles for land preparation and cultivation. These challenges can also be fixed to some extent by DSR practice since it demands less manual labour. Dry-DSR is promising for the regions with greater water scarcity such as rainfed uplands. This practice can be successfully implemented in spring rice due to the reduction of weed infestation and efficient use of water. DSR has been reported to be eco-friendly and sustainable

as it emits less methane which is a prominent greenhouse gas. At present, more detailed studies and specialized researches are required at the local level on diverse aspects of DSR such as variety selection, seeding rate, management of weed, water and nutrients alongside diseases and pests. Concerned authorities like International Rice Research Institute (IRRI), Nepal Agriculture Research Council (NARC) and National Rice Research Programme (NRRP) should facilitate the research and extension programmes. Development and dissemination of technology (improved seeds, herbicides, weeder, seeder, cultivator, harrows) should be prioritized. Government should provide subsidies and insurance to motivate farmers to adopt DSR which may uplift the living standards of marginalized farmers.

## Acknowledgement

We would like to thank our parents, teachers and colleagues whose support and encouragement helped us complete this review.

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