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Anita Kumawat
ICAR-Indian Institute of Soil and Water Conservation, Dehradun, India

Seema Sepat
ICAR-Indian Agricultural Research Institute, New Delhi, India

AK Vishwakarma
ICAR-Indian Institute of Soil Science, Bhopal, India

Dinesh Kumar
ICAR-Indian Agricultural Research Institute, New Delhi, India

RH Wanjari
ICAR-Indian Institute of Soil Science, Bhopal, India

NK Sharma
ICAR-Indian Institute of Soil and Water Conservation, Dehradun, India

Devideen Yadav
ICAR-Indian Institute of Soil and Water Conservation, Dehradun, India

Correspondence
Anita Kumawat
ICAR-Indian Institute of Soil and Water Conservation, Dehradun, India

Management practices for enhancing resource use efficiency under direct seeded rice - A review

Anita Kumawat, Seema Sepat, AK Vishwakarma, Dinesh Kumar, RH Wanjari, NK Sharma and Devideen Yadav

Abstract
The transplanted puddled rice (TPR) is a water, labour and energy intensive practice, and also emits vast amount of green-house gasses (GHG), particularly methane. The water guzzling nature of TPR and escalating labour prices drives towards the search for alternative methods of rice production. Among different methods of rice cultivation, direct-seeded rice (DSR) received much attention in this way; however, major constraints in DSR are identified as poor crop establishment, weed infestation, nematode occurrence and imbalanced nutrient and faulty water management practices. This paper summarises the improved production technologies for DSR viz. precision levelling, early-maturing varieties, seed priming, effective water, nutrient and weed management. It is evident from the review that grain yield, water productivity and net income could be enhanced by laser land levelling as compared to traditional levelling. Alternate wetting and drying method of irrigation in DSR resulted in less water requirement without any yield penalty. Application of Pendimethalin @1 kg a.i. /ha as pre-emergence followed by post-emergence application of bispyribac sodium @ 25g a.i./ha recorded higher grain yield and better weed control efficiency. Use of *Trichoderma viride* @ 2.5 kg/ha was found effective to control nematode infestation in DSR. Moreover, compared to TPR, DSR had less methane emission and global warming potential. Thus, DSR is a feasible alternative to TPR with a good potential to save water, reduce labour requirement, and to mitigate the climatic risks in Indian agriculture.

Keywords: Alternate wetting and drying, Brown manuring, DSR, Green-house gases, IWM, Laser land levelling, Nutrient management and Seed priming

Introduction
Rice (*Oryza sativa* L.), a staple food for more than half of the world population, is an important crop to provide food security and livelihoods for millions across the globe. Rice provides 30–75% of the total calories to more than 3 billion Asians and is commonly grown by transplanting seedlings into puddled soil in Asia. This production system is labour, water and energy-intensive and is becoming less profitable as these resources are becoming increasingly scarce (Kumar and Ladha, 2011) [30]. However, the advantages of the traditional transplanted puddled rice (TPR) system of crop establishment include increased nutrient availability (e.g. iron, zinc, phosphorus), weed suppression, easy seedling establishment and creating anaerobic conditions to enhance nutrient availability (Surendra *et al.*, 2001) [52]. The TPR, leads to higher losses of water through puddling, surface evaporation and percolation (Farooq *et al*., 2011) [15]. Repeated puddling adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in subsurface layers, and forming hard pans at shallow depths, all of which can negatively affect the following crops in rotation (Tripathi *et al*., 2005) [53]. Huge water inputs, labour costs and labour requirements for TPR have reduced profit margins (Pandey and Velasco, 1999) [35]. TPR has high labour demands for uprooting nursery seedlings, puddling fields and transplanting seedlings into fields. In consequence, imminent water crisis, water-demanding nature of traditionally cultivated rice and climbing labour costs ramble the search for alternative management methods to increase water productivity, system sustainability and profitability (Joshi *et al.*, 2013) [25]. Direct-seeded rice (DSR) technique is becoming popular because of its low-input demanding nature. DSR is a major opportunity to change production practices to attain optimal plant density and high water productivity in water scarce areas (Farooq *et al*., 2011) [15]. However high weed infestation is a major constraint for broader adoption of DSR (Rao *et al.*, 2007) [40]. Likewise, micronutrient deficiencies such as Zn and Fe, due to imbalanced N fertilization and high infiltration rates in DSR, are of major concern (Gao *et al.*, 2006) [16]. Nonetheless, it can be grown successfully through selection of suitable cultivars, precise irrigation management, integrated nutrient management, effective weed management, adoption of improved farm equipment and

conservation agriculture practices. Accordingly, DSR is a feasible alternative to conventional TPR with good potential to save water, reduce labour requirement, mitigate green-house gas (GHG) emission and adapt to climatic risks (Pathak *et al.*, 2011) [37].

Direct-seeded rice (DSR)

Direct seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq *et al.*, 2011) [15]. DSR is becoming popular because of its potential to save water and labour (Gupta *et al*., 2006) [19]. Currently, DSR covers 23%, 26% and 28% of the total rice area in World, South Asia and India, respectively (Rao *et al.*, 2007) [40]. It occupies a major area in eastern zone comprising of Assam, Bihar, Eastern M.P., Orissa, Eastern U.P. and West Bengal in India. These lands are generally dry, unbunded, and directly seeded. Direct seeding avoids three basic operations, namely, puddling, transplanting and standing water. Depending on water and labour scarcity, farmers are changing either their rice establishment methods only or both tillage and rice establishment methods. There are essentially three methods of DSR establishment, based on the physical condition of the seedbed and seed, (i) dry seeding (ii) wet seeding (iii) water seeding (Table 1). Dry direct seeding may offer one opportunity, with potential to save labour, reduce drudgery and improve resource-use efficiency (Clarke *et al*., 2018; Joshi *et al*., 2013) [8, 25]. In several studies, it is reported that both dry and wet-DSR have the potential to reduce water and labour requirement as compared with TPR. Tabbal *et al.* (2002) in their on-farm studies in the Philippines observed on average 11–18% of savings in irrigation water in wet-DSR as compared with TPR when irrigation application criteria was same for both establishment methods. Similarly, 10–50% savings in water have been claimed in dry-DSR over TPR from India when irrigation was tensiometer-based at 20 kPa at 20-cm depth (Yadav *et al*., 2011) [57]. Similar to saving in water, DSR can also reduce total labour requirements from 11% to 66% depending on season, location, and type of DSR (Kumar *et al*., 2009) [31].

Table 1: Classification of direct seeded rice system

DSR system	Seed condition	Soil condition and environment	Seeding pattern	Where practiced	Reference
Dry-DSR	Dry	Dry soil, mostly aerobic	Broadcasting, Drilling or sowing in rows	Mainly in rainfed area, some in irrigated areas with water control	Tuong *et al.* 1993
Wet-DSR	Pre-germinated	Puddled soil, may be aerobic or anaerobic	Various	Mostly in irrigated areas with good drainage	Weerakoon *et al.*, 2011 [56]
Water seeding	Dry or Pre-germinated	Standing water, mostly anaerobic	Broadcasting on standing water	In irrigated areas with good land levelling and in areas with red rice problem	Smith and Shaw, 1966 [50]

Major drivers of the shift from TPR to DSR

TPR is a major user of freshwater which is two to three times more than other cereals (Barker *et al.*, 1998) [3]. Rice consumes about 50% of total irrigation water used in Asia and accounts for about 24–30% of the withdrawal of world total freshwater (Bouman *et al.*, 2007) [6]. Globally, water is becoming an increasingly scarce resource and availability of water for agriculture is decreasing. Therefore, the need of hour is water use efficient crop production technology, which inherently requires less water. DSR provides such opportunity for saving water. Further, rapid economic growth has increased the labour demand in non-agricultural sectors, resulting in reduced labour availability for agriculture (Dawe, 2005) [11]. The increasing labour scarcity leads to the increase in labour wages which has increased by 20% per annum (CACP, 2013). Because of increasing labour wages, TPR has become uneconomical, and therefore, farmers are forcing to opt for a shift in rice establishment method from TPR (25–50 person per ha/day) to DSR (5 person per ha/day). Although labour and water are the major drivers for the shift from TPR to DSR, economic incentives brought out by DSR through crop intensification is another reason for the rapid adoption of DSR. For example, in the Vietnam and Philippines, DSR facilitated double cropping instead of a single crop of TPR (Pandey and Velasco, 2002) [34]. Some farmers can even grow a third crop of rice with supplemental irrigation during December to February (Pandey *et al*., 2007) [36]. Notably, the availability of high-yielding short-duration varieties and new herbicides for weed control largely made this shift technically viable (Pandey and Velasco, 2002) [34].

Stagnating crop and factor productivity and a deteriorating resource base in cereal systems have led to the encouragement of conservation tillage-based agriculture. Conservation tillage has a significant positive impact on wheat productivity, profitability, resource-use efficiency and farmer's livelihood, especially in those areas where the rice harvest is normally delayed (Erenstein and Laxmi, 2008) [12]. Wider adoption of zero tillage in wheat occurred because of both increased yield and reduction in production cost (Gupta and Seth, 2007) [18]. However, unlike wheat, rice continues to be widely grown under conventional intensive tillage and transplanting, and also delays the planting of wheat. To realize the full benefits of zero tillage efforts are being made to develop zero-tillage rice followed by zero tillage wheat; commonly referred to as "double zero tillage." Furthermore, puddling result in a complete breakdown of soil aggregates, destruction of macro pores and formation of a hard pan at shallow depth. On an average, 9% higher wheat yield was reported when wheat was grown after dry-DSR than after TPR. The main reason reported for the lower grain yield of wheat grown after TPR was poor root development in a suboptimal soil physical environment resulting from puddling (Kumar and Ladha, 2011) [30]. Ishaq *et al.* (2001) [23] observed that subsoil compaction resulted in a reduction in both water and nutrient use efficiency in wheat by 38% owing to decreased root length. The physical limitations imposed by puddling were implicated as the major causes of the inferior performance of upland crops following rice. Another reason for shifting to DSR is emission of greenhouse gases under TPR. Rice farming is believed to be the leading anthropogenic source of methane (CH_4), contributing 20% in global warming (IPCC, 2007) [21]. CH_4 has been reported to account for 95% of total CO_2-equivalent emissions from paddy fields and accounts for 10-20% of total global annual CH_4 emissions (Reiner and

Aulakh, 2000) [41]. CH_4 emission starts at redox potential of soil below -150 mV and is stimulated at less than -200 mV (Jugsujinda *et al.,* 1996) [26]. CH_4 emission can be controlled by various management practices such as mid-season drainage has been reported to reduce methane emissions by 50%. Similarly, direct seeding has the potential to decrease CH_4 emissions up to 18% (Wassmann *et al.,* 2004; Corton *et al*., 2000) [55, 9]. Bhatia *et al*. (2011) [4] reported lower CH_4 emission and global warming under DSR over the TPR while, higher N_2O emission was recorded under DSR with brown manuring as the addition of organic matter to soil increased the decomposition rate. It is therefore important to identify alternatives to puddling with improved production technologies, especially in those regions where water is becoming scarce and an upland crop is grown after rice.

Management practices for enhancing productivity under DSR

The production technology of DSR revolves around precise land leveling, seed priming and sowing for good crop establishment, choice of cultivars, effective nutrient, irrigation, weed and nematode management. This approach is being practiced successfully across the globe and in India, it is practiced in Punjab, Haryana, U.P., Bihar, Terai of Uttaranchal, Orissa, Chhattisgarh and West Bengal, (Gupta *et al.,* 2006) [19]. The most important prerequisites production technologies for a successful crop of DSR are summarized below:

Precise land leveling

The lack of uniform water distribution associated with unevenness of land, causing large yield variability within a field and leads to poor establishment of DSR (Kumar and Ladha, 2011) [30]. In IGP of India on average 8-15 cm deviation in field level in mostly traditionally-leveled fields is observed. This results in poor crop establishment due to unequal distribution of water in soil profile and inundation of newly germinating seedlings at initial stages (Gopal *et al.,* 2010) [17]. Laser land leveling facilitates uniform and good crop establishment, permits precise and uniform water distribution, reduces weed infestation, increases cultivation area (2-3%), improves input-use efficiency (water, nutrients, and agrochemicals), and hence crop productivity (Jat *et al.,* 2006) [24].

Seed priming and sowing for good crop establishment

After shifting from TPR to DSR, crop establishment becomes a critical factor affecting subsequent growth, development and yield in rice. One of the most pragmatic approach to improve emergence and stand establishment is seed priming (Phill, 1995), a promising solution to poor stand establishment in DSR. It involves partial hydration to a point where germination-related metabolic processes begin but radicle emergence does not occur (Farooq *et al.,* 2009) [13]. Seed priming techniques, such as hydro-priming, osmo-hardening, hardening and priming with growth promoters have been successfully employed in rice to hasten and synchronise emergence, achieve uniform stands, and improve yield and quality. Farooq *et al.* (2011) [15] reported that osmo-hardening of fine grain rice seeds with $CaCl_2$ followed by hardening and osmo-hardening with KCl reduced the mean emergence time as compared to the untreated seeds.

Sowing time, seed rate and seeding depth

The sowing should be terminated before 10-15 days of onset of monsoon between end of May to third week of June to facilitate the early root establishment so that crop couldcompetewith emerging weeds and also permit timely sowing of succeeding crop. Optimum time of planting results in improved rainwater use efficiency by 40-50% and enhances the total productivity of cropping system up to 30% (Kumar and Ladha, 2011) [30]. Optimum seed rate with zero till ferti-drill for fine grains, basmati cultivars is 15-20 kg/ha, coarse grains 20-25 kg/ha and for hybrids 8-10 kg/ha. For broadcasting a higher seed rate (25-30 kg/ha) is required. In the IGP, a seed rate of 20–25 kg/ha has been found optimum for medium-fine-grain rice cultivars with a spacing of 20-25 cm between rows and 5 cm within rows (Sudhir *et al.,* 2007) [51]. Seeding depth is also critical for all rice varieties but more for semi-dwarf varieties because of their shorter mesocotyl length compared to conventional tall varieties (Blanche *et al.,* 2009) [5]. Placement of seeds too deep or shallow depth adversely affects the dynamics of seed germination due to weak coleoptiles and rapid drying of the soil surface in peak summers (Gopal *et al.,* 2010) [17]. Therefore, rice should not be drilled deeper than 2.5 cm to maximize uniform crop establishment (Gopal *et al.,* 2010; Kamboj *et al.,* 2012) [17, 27].

Planting machinery

Conservation agriculture-based machinery such as power tiller operated seeder (PTOS) and bed former or planter (BP) result in early planting, increased yield, reduced production costs and water requirement. Bed planting improves water distribution and irrigation efficiency, and reduces weed infestation and crop lodging. PTOS can play an important role to enhance farmer's income, minimize production cost, and facilitates crop-diversification. With these precise seed-metering planters, better crop establishment with a lower seed rate and more precise plant to plant spacing can be done (Gupta *et al.,* 2006) [19]. Recently, different machines have been evaluated and refined for seeding under loose residue, especially after combine harvest in South Asia as turbo happy seeder and rotary disc drill (Singh *et al.,* 2008, Gopal *et al.,* 2010) [45, 17]. Iqbal *et al.* (2014) [22] reported that grain yield of DSR through PTOS tillage system performed best and significantly higher than conventional methods.

Choice of cultivars

Selection of cultivars plays an important role to get the desired yield and depends on the availability of irrigation water and soil types. Under irrigated sandy loam soil condition, early to medium duration varieties (100–135 days) may be preferred where as in case of heavy textured clay; medium to late maturing varieties (135-165 days) should be grown. The cultivars having good mechanical strength to facilitate early emergence of the seedlings under crust conditions, early seedling vigour for weed competitiveness, efficient root system for anchorage and to tap soil moisture from lower layers in peak evaporative demands, lodging resistance and yield stability over planting times are desirable traits for DSR (Joshi *et al.,* 2013) [25]. Varieties suitable for DSR in different regions of India are listed in Table 2.

Table 2: Rice varieties and hybrids suitable for DSR

Regions	Suitable Genotypes for DSR
Bihar	Rajshree, MTU-7029, Satyam, Rajendra Masuri-I, NDR-359, Prabhat, Birsa dhan-101, Birsa dhan -104
Eastern UP	NDR-359, Sarjoo-52, Muhsoori, Swarna, MTU-7029, Moti, Pusa-44, KRH-2
Haryana, Punjab, Western UP	Pusa-1121, Pusa-2511, PRH-10, Pusa Basmati-1, Pant Dhan-12, Sharbati, PHB-71
Tarai, Uttarakhand	Nidhi, UPRI-92, Narendra-359, PD-4, Sarrvati, PR-113, HKR-120, Sarjoo-52

Efficient nutrient management

In DSR, availability of N, P, S and micronutrients such as Zn and Fe, is likely to be a constraint. In addition, loss of N due to denitrification, volatilization and leaching is probably to be higher in dry-DSR than in TPR (Davidson, 1991) [10]. To compensate these losses higher dose of N (22.5-30 kg/ha) is suggested in DSR. P and K and one-third N should be applied as basal and remaining two-third dose of N should be applied in splits in equal parts at active tillering and panicle initiation stages (Kamboj *et al.,* 2012) [27]. Kumawat *et al* (2016) [32] reported higher grain yield and net returns, when number of split application of N increases. Two to three split applications of N increased the grain yield by 30% - 75% over the single basal application (Sengxua *et al.*, 2018) [42]. Further, N can be managed using a leaf colour chart (LCC) and SPAD meter (Alam *et al.,* 2005) [1]. Slow-release or controlled-release N fertilizers (CRFs) offer better match to crop N demand to reduce its losses and improve N use efficiency and yield (Shoji *et al.*, 2001) [44]. Split application of K with 50% as basal and 50% at early panicle initiation stage has also been suggested for DSR in medium-textured soil (Kumar and Ladha, 2011) [30]. Emergence of zinc (Zn) deficiency is now widespread in most of the rice growing soils. Basal application of 25–50 kg/ha zinc sulphate heptahydrate is found to be the best to avoid its deficiency. However, if a basal application is missed, the deficiency can be corrected by topdressing up to 45 DAS. For foliar application, 0.5% zinc sulphate two to three times at intervals of 7-15 days just after the appearance of deficiency symptoms is recommended. Under aerobic condition, deficiency of iron (Fe) is more pronounced due to oxidation of available ferrous form to unavailable ferric form in soil. For correction of Fe deficiency foliar application of 9 kg Fe per ha in three splits (40, 60, and 75 DAS) as foliar spray (3% of $FeSO_4.7H_2O$ solution) has been found to be effective (Pal *et al*., 2008). Yadav *et al.* (2011) [57] revealed that both soil and foliar application of 50 kg/ha + 2 foliar spray of 2% $FeSO_4.7H_2O$ results in higher grain yield, net returns and benefit cost ratio and was comparable to sole soil application of 100 kg $FeSO_4.7H_2O$ ha^{l} and 3 foliar spray of 2% $FeSO_4.7H_2O$.

Precise irrigation management

New water cannot be created; thus, we have to conserve and make judicious use of every drop. For this, two possible options are to minimize water losses through better management and improve water use efficiency. Precise water management, particularly during crop emergence phase is crucial in DSR (Balasubramanian and Hill, 2002) [2]. Apply pre-sowing irrigation for crop establishment; first irrigation can be applied 7-10 days after sowing and subsequent irrigations at interval of 5-7 days depending on the soil type. During active tillering phase and reproductive phase, optimum moisture is required to harvest optimum yields from DSR. A study conducted by Humphreys *et al.* (2010) [20] in Ludhiyana Punjab on clay loam soil indicated That 20 kPa soil water tensions at 20 cm depth are safe for alternate wetting and drying (AWD) irrigation scheduling. This study showed that 33-53% irrigation water can be saved in dry-DSR with AWD as compared with TPR without compromising grain yield. Pathak *et al*. (2011) [37] conducted an experiment on water input, water productivity and net profit from different crop establishment technologies at Western Uttar Pradesh and Haryana. He reported that water input in reduced till DSR (RT-DSR) and ZT-DSR was 6-21% less compared to the CT-TPR establishment method. The water productivity was also higher with more net profit in RT-DSR and ZT-DSR than CT-TPR method. The DSR crop saved 32% water compared to transplanted rice without any yield penalty. Irrigation scheduling at 10 kPa throughout the growing season except 40 kPa during tillering to flowering resulted 11.5% higher water use efficiency in DSR over the saturated condition (Kumawat *et al*., 2017) [33]. Pressurized irrigation systems also have the potential to increase irrigation water use efficiency by providing water to match crop requirements, reducing runoff and deep drainage losses, and generally keeping the soil drier, reducing soil evaporation and increasing the capacity to capture rainfall (Camp, 1998) [7]. Sprinkler irrigation results in increased grain yield and reduced irrigation water use by 30-70% (Kato *et al*., 2009) [28].

Weed management

High weed infestation is the major bottleneck in DSR, especially in dry field conditions. Estimated losses from weeds in rice is estimated to be around 10% of total grain yield; however, can be in the range of 50 to 90% with poor grain quality (Rao *et al*., 2007; Singh *et al.*, 2009) [40, 47]. In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively (Ramzan, 2003) [39], and up to 68–100% for direct seeded Aus rice. Weeds are more problematic in DSR because emerging DSR seedlings are less competitive with concurrently emerging weeds and the initial flush of weeds is not controlled by flooding in Wet- and Dry-DSR (Rao *et al*., 2007) [40]. Weed flora diversity is greater under DSR and more than 50 weed species cause yield losses in DSR and (Singh *et al*., 2005) [46]. The dominant weed species reported by the farmers in DSR fields are listed in Table 3.

Table 3: Important weeds associated with direct seeding rice crop

Weed group	Weed species
Grasses	*Echinochloa colona, Echinichloa crusgalli, Digitaria setigera, Eleusine indica, Echinochloa glabrescens, Ischaemum rugosum, Digitaria ciliaris, Oryza sativa (weedy rice), Leptochloa chinensis, Paspalum distichum*
Sedges	*Cyperus iria, Cyperus difformi, Cyperus rotundus, Fimbristylis miliacea*
Broadleaf weeds	*Monochoria vaginalis, Ipomoea aquatic, Sphenoclea zeylanica, Ludwigia octovalvis, Ludwigia adscendens, Eclipta prostrate, Commelina benghalensis*

Integrated weed management

Integrated weed management is desirable for effective and sustainable weed control in Dry- DSR (Rao *et al.*, 2007) [40]. Stale seed bed is one of the cultural technique in which, after initial seedbed preparation, the field is irrigated and left unsown to allow weeds to germinate. Following emergence, weeds are killed either by a nonselective herbicide or by carrying out tillage prior to the sowing of rice. This technique not only reduces weed emergence but also reduces the soil weed seedbank (Rao *et al.,* 2007) [40]. A 53% lower weed density in dry-DSR after a stale seedbed was recorded over control (Singh *et al.,* 2009) [47]. Similarly, sesbania co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield and also facilitate atmospheric nitrogen fixation (Kamboj *et al*., 2012) [27]. It involves seeding rice and sesbania crops together and then killing sesbania with 2, 4-D ester @ 0.50 kg/ha at about 25-30 DAS. Singh *et al*. (2007) [49] reported that brown manuring reduced broadleaf and grass weed density by 76–83% and 20–33%, respectively, and total weed biomass by 37–80% compared with a sole rice crop. This may largely be due to the rapid growth of sesbania and to some extent, mulch effects of its biomass. A variety of herbicides have also been screened and found effective for weed control in DSR. Glyphosate (1 kg a.i./ha and paraquat (0.5 kg a.i./ha) are recommended for pre-plant/burndown application (Gupta *et al.,* 2006) [19]. Pendimethalin (1.0 kg a.i./ha), oxadiargyl (0.09 kg a.i./ha) and pyrazosulfuron (0.02 kg/ha) have been reported to be effective preemergence herbicides to control weeds in dry DSR (Kumar and Ladha, 2011) [30]. Good soil moisture is essential for the activation of preemergence herbicides. Likewise, post emergence application of bispyribac sodium (25 g a.i./ha) was found very effective on most of the grasses. Bispyribac works well in saturated soil conditions (Kamboj *et al.,* 2012) [27]. Penoxsulam, Fenoxaprop-ethyl, Cyhalofop-butyl, Propanil, Ethoxysulfuron etc. post emergence herbicides are also used for weed control in DSR. Sometimes one or two spot hand weedings may be necessary to remove weeds that have not been controlled by other weed control methods. For mechanical weeding, rotary weeders and cono weeders have been found effective. Singh *et al.* (2015) [48] reported higher yield attributing characters and yield in sequential application of pendimethalin followed by bispyribac herbicides over adoption of single weed management practices.

Nematode management

The most damaging soil-borne pathogen for DSR is root-knot nematode (RKN) *Meloidogyne graminicola*, is incapable of entering the rice roots under flooded conditions, although it can survive for extended periods and attacks rice roots under DSR. Kreye *et al.* (2009) [29] studied the impact of nematicides and biocides on the grain yield of rice, and concluded that the grain yield was maximum and galling of RKN in roots less under DSR crop when treated with biocide (nemagel or dazomet @ 50 g a.i./m^2). For poor farmers' use of natural plant derived biocides, such as, that from neem (Azadirachta indica) as it is cheaper, indigenously available and eco-friendly product. Shanmuga-Priya (2015) [43] reported that there was significant increase in root weight and grain yield in *T. viride* and carbofuran treatments compared to untreated treatments.

Conclusion

DSR with suitable management practices has potential to produce sustainable yield and appears to be a viable alternative to overcome the problem of water and labour shortage in Indian conditions. Despite controversies, if properly managed, comparable yield may be obtained from DSR compared with TPR. It can be concluded that DSR can be grown successfully with suitable cultivars selection, seed priming and adoption of precise seeding and land-leveling machinery. Similarly, precise management of irrigation, nutrient, weed and nematode are the keys to obtain higher yield under DSR. It is a feasible alternative to TPR with good potential to save water, energy and labour requirement, and to mitigate the impact of changing climate. It saves around 34% labour and 50% water but it could be successful if accompanied with effective weed control measures. Adoption of improved farm equipment leads to increased grain yield in DSR through better crop establishment.

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