The Pharma Innovation Journal 2023; 12(6): 5034-5043

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(6): 5034-5043

www.thepharmajournal.com
Received: 08-03-2023
Accepted: 12-04-2023

Direct seeded rice: Present need for future

Arti Bhandari, Dr. Pankaj Nautiyal, Dr. Deepak Rai, Manish Madhwal, Manish Deorari, Shivam Bandhani, Akshita Nautiyal, Shewta Gusain, Amar Raturi and Shifa Rayeen

Arti Bhandari
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Dr. Pankaj Nautiyal
KVK, ICAR-VPKAS, Uttarkashi, Uttarakhand, India

Dr. Deepak Rai
KVK, ICAR-IISR, Lucknow, Uttar Pradesh, India

Manish Madhwal
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Manish Deorari
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Shivam Bandhani
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Akshita Nautiyal
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Shewta Gusain
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Amar Raturi
Shri Guru Ram Rai University, Dehradun, Uttarakhand, India

Shifa Rayeen
VCSG, Uttarakhand University of Horticulture & Forestry, Uttarakhand, India

Corresponding Author:
Dr. Pankaj Nautiyal
KVK, ICAR-VPKAS, Uttarkashi, Uttarakhand, India

Abstract
The years happening next are going to be tough for global rice production. Availability of resources for rice production are declining. Transplanting rice (TPR) is a labor, water and energy intensive system. TPR contributes to methane emission, deteriorates soil physical and chemical properties and is an obstacle in gaining potential yield from succeeding upland crops. Present scenario revealed that several countries have shifted from TPR to DSR (Direct seeded rice) technique for rice establishment. DSR is a suitable and convenient substitute to conventional puddled rice. DSR adoption over TPR helps in (1) saving water; (2) reduces labor requirement; (3) higher cost benefit ratio; (4) less drudgery; (5) similar yields; (6) improvising soil physical and chemical properties; (7) offers early crop maturation; (8) a reduction in methane emission; and (9) enhance sustainability. Despite these advantages (1) weed infestation; (2) high spikelet stability; (3) poor stand crops; (4) less knowledge management skill; causes yield variation in DSR. More and more continuous research and extension activities should be made on DSR to draw higher benefits.

Keywords: Direct seeded rice, transplanted, substitute, conventional puddled rice, intensive, infestation, deteriorates, cost benefit ratio, sustainability

Introduction
Rice botanically known as *Oryza sativa*, belongs to family poaceae. Indo-Burma (South-eastern Asia) is considered as its center of origin, having chromosome number 12 (2n=24) of panicle inflorescence, with fruit type caryopsis. We all know that rice is a grain producing cereal crop consumed as a staple food, globally. One of the oldest cereal records in the history of mankind. The total production during 2021-22 is estimated at a record 127.93 million tonnes (https://pib gov.in) and staple food for more than 3.5 billion people in the world (www.nationalgeographic.org).

Around 110 countries commercially grow rice. In Asia, about 90% of the global rice production and consumption is there (krishi.icar.gov.in). Major countries responsible for rice production are China (148.3 million metric tons), India (122.27 million metric tons), Indonesia (35.3 million metric tons) (www.statista.com). On the other hand, India is considered the top exporter in the world, at 18.75 million metric tons as of 2021-22 (www.statista.com).

Production of rice through transplanting seedlings from nursery to puddled field for further growth is a traditional method, practiced in India from ages, termed as Transplanted Puddled Rice (TPR). The TPR system of rice establishment requires a puddled field for transplanting i.e high water use, more laborers for raising and transplanting seedlings from nursery to puddled field which directly increases production cost. Due to high water requirements in the TPR system, there is huge exploitation of groundwater, which creates water scarcity in the states where paddy cultivation is performed by excessive pumping, which causes contamination of toxic geogenic contaminants such as arsenic and fluoride.

Taking an example of Punjab, it had around 2.44 million acre feet of groundwater in 1984; but within 3 decades, it went down upto minus 11.63 million acre feet, which is one of the major topics of concern. Only reason is over exploitation of groundwater. Going to the depth of this problem, the exact reason behind groundwater depletion is paddy cultivation at large scale followed by Punjab after the green revolution (www.grainmart.in). In the TPR system rice requires a high amount of water for transplanting, puddling, irrigation, also water losses occur by seepage, percolation, evaporation etc. It is estimated that in the TPR system, rice consumes 3000-5000 liters of water to produce 1 kg of rice (Barker *et al*., 1998) [7].

Undoubtedly, water is a very important natural resource gifted by god to living beings, but water is decreasing year by year in high amounts, which is a global issue raising every year as a warning for the future. On the other hand, rice production in large scale is highly dependent on the irrigated lowland rice cultivation, which creates fresh water scarcity, water pollution, chemical residues on water making it unsuitable for drinking purposes.

Not only water scarcity, another problem mostly faced by farmers in the TPR system is labor shortage, as labor requirement is more in this system. It creates labor scarcity and high labor cost, thus directly decreasing cost-benefits ratio. According to indianexpress.com, in the times of pandemic (COVID in 2019), labor shortage makes Punjab, Haryana farmers switch from paddy to cotton as mostly seasonal migrants are from Bihar and Uttar Pradesh (approx.10 lakh labors) .

Water scarcity and labor shortage are not only problems in TPR, other than these, soil health degradation, methane gas emission, nitrogen loss, high production cost are some of the major issues of concern here. Lowland rice cultivation is considered as a major source of methane gas emission, which contributes around 48% of the total greenhouse gasses emitted by agricultural sectors.

The International Rice Research Institute has especially introduced "aerobic rice" varieties, brought in with an aim of growing rice under non-puddled, non-flooded and on non-saturated soil conditions with the target of "more rice with limited amount of water".

Literally aerobic rice, is a planting system practiced in lowland rice cultivation without puddling, which requires less water at the time of irrigation as compared with the TPR system. Rice is planted directly in aerobic soil without puddling, after sowing it is necessary to provide supplementary irrigation and fertilizers are used for obtaining higher production.

Hence, adoption of DSR over the TPR system for rice establishment can be a viable, feasible, economical, eco-friendly and sustainable opportunity for farmers. DSR improvises rice productivity, increases water use efficiency in rice cultivation, short out the labor shortage problem, reduces methane gas emission, less drudgery, offering early crop maturity (7-10 days), efficient and proper placement of seed and fertilizer, improvising soil physical and chemical properties, promotes higher cost-benefits ratio.

So, it is necessary now to adopt DSR aerobic rice cultivation over TPR, however evidence is emerging that the continuous rice-wheat systems are exhausting the natural resources base (Duxbury *et al*., 2000) [9], which also provides a major hindrance to gain potential yield of crops in the rice-wheat cropping system.

Newspaper Headline Regarding Rice Cultivation

According to "Tribune News Service" (Amritsar, June 16, 2022) [10] 'The District Agriculture Department' organized a program in Khalchian Village, Punjab to encourage farmers to adopt direct seeding of rice (DSR) technique and to provide technical know-how to them in this regard. Agriculture Extension Officer Satwant Kaur said farmers in Khalchian Village have sown (www.tribuneindia.com).

According to "The Time of India"(May 3, 2022): Punjab CM Bhagwant Mann urges farmers of native villages to adopt DSR technology on maximum area' which promotes cultivation of paddy by using less amount of water from his native village Satauj in Sangrur district.

According to drishtiias.com (May 6, 2022): Recently, the Punjab government announced Rs 1500 incentive per acre for farmers opting for DSR. In 2021, 18% (5.62 lakh hectare) of the total rice area in the state was under DSR against the government.

Direct Seeding Rice (DSR) System

Several countries of Southeast Asia have been shifted from TPR to DSR cultivation system (Pandey and Velasco, 2002) [11]. Shift from TPR to DSR is due to water scarcity and expensive labor (Chan and Nor, 1993) [12].

DSR is an alternative and effective approach with a purpose to switch from conventional to conservation agriculture in rice cultivation. In contrast with TPR, DSR advocates minimum use of resources, time, energy, fuel, machinery inputs and labor. It avoids nursery raising, seedling uprooting, puddling, transplanting and thus reduces the labor requirement (Pepsico International, 2011), which reduces water consumption level upto 30% (0.9 million liters per acre). Higher grain yield recorded under DSR (3.15 tonnes per hectare) than TPR (2.99 tonnes per hectare), which increases panicle counts, higher weight of 1000 kernels and reduces sterility percentage (Sarkar *et al*., 2003) [14]. DSR technique provides growers an advantage of 10-15 days earlier crop maturation, conserving water upto 35-40% in comparison with TPR system. DSR decreased the production cost by Rs 3000 per hectare, with an increment in yield by 10% (Singh *et al*., 2012) [16]. DSR technique decreases the cost of nursery raising, puddling and labor charges therefore, helps in reducing cost of cultivation automatically.

Hence, adoption of DSR technique gifts farmers numerous benefits of timely establishment of crop by shorting the maturation days (10-15 days), minimizes the count of labors requirement, production cost, fuel, energy, drudgery of labors, upgrading soil physical condition by avoiding the puddling task, as practiced under TPR system.

Besides saving water, labor, crop maturation days, DSR is a beneficial concept to diminish methane gas emission. As we all know, the TPR system of rice cultivation is a major inception for increasing the concentration of greenhouse gas (GHG) in the environment, specifically methane, giving rise to global warming. Also the DSR system demonstrated better nitrogen use efficiency.

A two year field experiment was conducted for the evaluation of GHG decrement, water and labor saving potential of the DSR crop field by comparing with TPR in three villages of Jalandhar, Punjab, India (H Pathak, S. Sankhyan *et al*., 2013) [17], analyzing the result it showed that if the entire area of Punjab is converted from TPR to DSR, the GWP (Global Warming Potential) will be reduced by 16.6% of the present emission; result of the experiment also proclaim that human labor use gets reduced upto 45%, while of tractor use upto 58% in DSR as compared to TPR.

Different Methods of DSR

Dry-DSR, wet-DSR, water seeding and transplanting are the four methods used in the establishment of rice. Among the four, dry-DSR, wet-DSR, water-seedings are the methods in which seeds are directly sown in the field rather than

transplanting.
Direct seed sowing is the oldest method in rice establishment; before the 1950s it was common, but was gradually replaced by puddled transplanting (Grigg, 1974; Pandey and Velasco, 2005; Rao *et al*., 2007) [18, 19, 20-22].

Dry-DSR

Establishment of rice by directly sowing in field is a methodology practice in Dry-DSR, which can includes (1) broadcasting of seeds on non-puddled soil, ensuring conventional tillage (CT-dry-BCR) or zero tillage (ZT-dry-BCR), (2) using dibbling process in field (CT-dry-dibbledR), (3) or can be by drilling seeds in rows after conventional tillage (CT-dry-DSR).
Seed-cum-fertilizer drill is used in dry-DSR (for CT-dry and ZT dry DSR), after land preparation or in the zero tillage conditions, ensuring proper placement of fertilizer and drilling of seeds. For Bed-dry-DSR, a bed-planting machine is used, after land preparation, forms a bed (37 cm wide raised bed and 30 cm wide furrows), places fertilizer, and drills the seed on both sides of the bed in a single operation (Bhusan *et al*., 2007; Singh *et al*., 2009c) [21]. Seeding by drilling is an appreciable approach over broadcasting as it allows line sowing, minimizes weed infestation, saves time and seeds. In dry DSR, the seedbed is unpuddled (dry), having a soil environment mostly aerobic. This method is traditionally practiced in rainfed upland, lowland, and flood prone areas of Asia (Rao *et al*., 2007) [20-22], this method in irrigated areas, where there is water scarcity.

Wet DSR

Wet-DSR requires pre germinated seeds for sowing with a radicle varying in size from 1-3 mm on or into puddled soil. When pre germinated seeds are sown on the surface of puddled soil, the seed environment is mostly aerobic and this is known as aerobic Wet-DSR (Kumar and Ladha 2011) [23].
In both aerobic and anaerobic Wet-DSR, seeds are either broadcast (CT-wet-BCR (surface)) or sown in line using a drum seeder [CT- wet-Drum R (surface)] (Khan *et al*., 2009; Rashid *et al*., 2009) [24] or an anaerobic seeder [CT-wet-DSR (subsurface)] with a furrow opener and closer (Balasubramanian and Hill, 2002) [25]. Coating seed by calcium peroxide helps in improving oxygen around germinating seeds in controlled tillage wet-DSR, while seeds are immersed for 24 hours in water, in manual broadcasting, pre germination period is kept short (24-h soaking and 12-h incubation) to limit root growth for ease of handling (easy flow of sprouted seeds) and to minimize damage, ad is the case when a drum seeder is used for row seeding (Balasubramanian and Hill, 2002) [25]. A drum seeder is a simple manually operated implement for sowing rice seed on puddled soil, it consists of 6 drums, each of 25 cm length with diameter of 55 cm, connected one after the other on an iron rod having two wheels at the two ends (Khan *et al*., 2009) [24].
For the motorized blower, a 3.5-hp blower/duster is used. Attached with either a 1m long blow pipe or a 20-30-m- long shower blow pipe (Jaafar *et al*., 1995) [27].

Water seeding DSR

Water seeding has gained popularity in areas where red rice or weedy rice infestation is a cause of problem to farmers (Azmi and Johnson, 2009) [28]. In this sizing method, firstly seeds should be pre germinatined (24-h soaking and 24-h incubation) and then broadcasting them in standing water puddled (wet-water) or non puddled soil (Dry water seeding) for sowing. Heavier weight of seeds, drop them in standing water. This method is conveniently applicable in flood-occurring areas, or simply places where water cannot be drained out from the field.

Challenges with Opportunities in DSR

Weed infestation, poor crop stand, turning down of yield, availability of purposely developed varieties, nutrient availability, panicle sterility, pests/diseases and water management are some various challenges, creating obstacles for wide-scale adoption of DSR by farmers (Nguyen and Ferrero 2006) [29]. In order to overcome these challenges, we have several opportunities, these all are part of ideal management skills; which are briefly discussed below.

Ideal Management Skills Required

First and foremost, we have to make sure, is that place convenient to give out desirable outcomes of direct seeding rice. This method is being practiced successfully across various countries like Sri Lanka, Thailand, Malaysia and Philippines; Bangladesh, China, Brazil and some Caribbean countries (Pandey and Velasco 2002) [11]; southern Brazil, Chile, Venezuela, Cuba (Fischer and Antigua 1996) [31]. In rice producing states of India like Punjab, Haryana, Orissa, Bihar, Uttarakhand, Uttar Pradesh, Chhattisgarh, and West Bengal, a shift on the way towards DSR technology has been spotted in the past countable years due to appropriate and fitting eco-systems. Management begins from genotype and site selection, then after seedbed preparation, sowing time, precise water management, nutrient management, and weeds management is required. In DSR systems, soil type (Tripathi, 1996), weed management (Rao *et al*., 2007) [20-22] and land leveling (Kahlown *et al*., 2002) [33] are of primary importance.

Land Preparation

In DSR technology, it is foremost that land to be well prepared for-

- Uniform germination
- Better crop establishment
- Increasing water use efficiency
- Weed control
- Improving input use efficiency

Hence, well prepared land ultimately increases grains quantity. Rice is a kharif crop, thus ploughing in summer proves an efficient practice for controlling weeds infestation, good germination, increases water use efficiency, which lead to success of DSR technology.
Laser Land leveling, reduces times and water for irrigation, helps in smoothing soil surface, providing uniform depth and better crop establishment and development. Hence, laser Land leveling has a vital role for the success of DSR technology as it facilitates uniform germination, increases water use, improves cultivation (Dahiphale *et al*., 2017) [34], lowering weed infestation and hence enhances crop yield.

Convenient time for sowing

Time of sowing is important for determining crop production. Sowing seeds either on a flat or on raised beds are two types. But, the fields (beds) should not be affected by the weeds population and precisely leveled at the time of sowing (Joshi *et al*., 2013) [35].

Sowing timing is location specific, in Punjab it's between 1 June-10 June (Gill *et al*., 2006) [36], 5-15 June in Cuttack (Chandra *et al*., 1991), 15 June at New Delhi (Narayanaswamy *et al*., 1982) [38]. Generally, it is suggested that from 1-15 June is considered the best sowing period for coarse rice and from 15-30 June for basmati rice (Bhulkar *et al*., 2016) [39]. Simplest sowing period of DSR is around 10-15 days before monsoon onset (Kakraliya *et al*., 2016) [40].

Required Seed Rate

High seed rates are required in the DSR system, of 6-8 kg/acre (Kakraliya *et al*., 2016) [40]. In order to suppress weeds, high-seeds rates are mostly used in broadcasting (Moody, 1977) of 25-40 kg/ha (Kumawat *et al*., 2019) [43] with 20 cm tow to row distance (Dhillon 2018) [44]. Optimum seed rate with zero till Ferro drill for fine grains, basmati cultivars is 15-20 Kg/ha, coarse grains 20-25 kg/ ha and for hybrids 8-10 kg/ ha (G Anil Kuma Reddy *et al*., 2020) [45].

Selection of Cultivar

Cultivars should posses characteristics like early vigor, resistance to lodging, shorts duration, having good mechanical strength in the coleoptiles, efficient root system for anchorage and to tap soil moisture from lower layers in peak evaporative demands (Pantuwan *et al*., 2002) [46], greater drought tolerance.

Coarse and hybrid type varieties are- Arize 6128, PR- 114, 113, 124, PRH-10, RH 664, Pus 44, RH 2014, HKRH 1, 401, Sahyadri; Basmati type- Pusa 1121, CSR-30, Pusa Basmati -1,etc. were appropriate in DSR technology (Kakraliya *et al*., 2016) [40]. Whereas IR36 is a good drought tolerance variety (Joshi 2016) [48]. The Hansa variety with a mean yield of 56.57 q/ha with B-C ratio (Singh *et al*., 2012) [16] is a suitable variety in DSR.

Seed Priming

Seed priming is a pre-sowing seed treatment, where seeds are subjected to controlled hydration and drying for increasing germination rate with greater germination, dry matter accumulation, uniformity, increasing yield, for controlling seed borne disease/ insects, faster seedlings (Sachan *et al.,* 2016) [15].

Seed priming, an economical technology, has been successfully employed in several rice production systems, like DSR, to boost performance in drought prone areas (Rehman *et al*., 2015) [49]. Promising sol to poor stand establishment (Kashiwar *et al*., 2016) [50], acts as a sort of catalyst to germination in DSR (Bhatt and Kukal 2015) [51].

Hydropriming, osmopriming, hormonal priming, halopriming, drumpriming, bio priming, matrix priming, are techniques in seed priming. Halopriming with 2% Potassium nitrate with 50 ppm GA3 has good potential for crop establishment and sice's yield in both conventional and soil mulch DSR (Buta Singh Dhillion *et al*., 2021) [52].

Priming of seed with combination of ZnO-NPs, Na-Selenite & Na-selenate could be an available option for the risk mitigation in DSR (Saju Adhikariyi *et al*., 2022) [53]. Seed can be soaked in solution having fungicide. and antibiotics (Emisan and Stretom) for 15-20 hours (Gopal *et al*., 2010; Gupta *et al*., 2006) [54, 73], treatment of seeds with fungicide should be done post-soaking for controlling seed borne insects and disease.

Machinery for planting

In DSR, seed seeded by planter or seed cum fertilizer act as a trump card over traditional TPR, ensures labor burden minimization upto 50% (Joshi *et al*., 2013) [35], make sure proper covering of seeds with soil to a certain depth, which saves from being consumed by birds, less drudgery, early and timely sowing.

Crop transplanted with self-propelled walk behind (SWT) and by self-propelled four wheel (SFT) not only gave benefits by increasing net return and reducing labor need (Manes *et al*., 2013) [54]. Power tiller seeders (Kumawat *et al*., 2019) [43] and seedcum fertilizer can take more benefits from residual soil moisture which reduces irrigation, early and timely sowing, placing seed and fertilizer nutrients at suitable depth. For ZT-DSR, when any anchored residues are retained, then the same multicrop planter can be used for seeding (Kakraliya *et al*., 2016) [40]. Turbo Happy Seeder, Rotary Disc Drill are two common machines used for planting purposes in DSR.

Weed Management

A significant challenge to the persuasiveness of the DSR technique is weed interference, weed infestation consisting of different weed flora e.g. aquatic, semi- aquatic and terrestrial weeds. 350 weed species are reported only in rice (V. Singh *et al*., 2016) [56-60] and around 50 weed species are occupying DSR crop fields (Caton BP, 2003) [57], (Rao *et al*., 2007) [20-22].

Grasses are the most problematic weeds followed by sedges and broadleaf weeds, in the DSR crop field. Major weeds listed in the DSR crop are mentioned in Table1, 2 and 3. Due to the same time of emergence and same seedling size with rice, conditions favors weeds to grow rapidly and also unavailability of standing water in the field cannot provide suppressive effect to weeds as in TPR field. Yield loss ranges from 15-20% in DSR system due to weed infestation, but may exceed 50% yield loss in severe cases (Hasanuzzaman *et al*., 2019) [59] or even can results in, out-and-out crop failure, which almost always occurs after one hand weeding in fields of weed infestation. In DSR, weed competition critical period has been observed and recorded 14-41 days after sowing, hence if weeds are controlled at initial growth stage of rice it results in desirable productivity in DSR at the time of harvesting. Controlling weeds by hand weeding is labourios and time-consuming approach. While herbicides facilitate easier, timely, economical and convenient control of weeds in rice but also consider the higher cost, drudgery and lower efficacy of other weed control options (Sen *et al*., 2020) [60]. Constant herbicidal use develops into evolution of weed flora shift and also buildup herbicidal resistance in weeds. Therefore, the requirement of integrating weed management strategies and herbicidal application for controlling weed infestation in the DSR system is a must. On the other hand, while labeling environmental concerns, we have to adopt such methods which are ecologically and economically well founded. In integrated weed management, we have several methods like cultural, mechanical, biological and chemical, for controlling weed infestation, which are briefly described below-:

Weed Category 1-: Some Grass weed species of DSR

Scientific name	Common name	Family
Echinochloa colona	Wild rice	Poaceae
E-crus-galli	Barnyard grass	Poaceae
Eleusine indica	Goosegrass	Poaceae
Leptochola chinensis	Sprangletop	Poaceae
Digitaria sanguinalis	Large crabgrass	Poaceae
Bracheroa ramose	Signal grass	Poaceae
Cynodon dactylon	Bermuda grass	Poaceae
Dactyloctenium aegyptium	Crown foot grass	Poaceae

Source: (Singh *et al*., 2016) [56-60]

Weed Category 2: Some of the common broadleaf weed of DSR

Scientific name	Common name	Family
Alternanthera Sessilis	Khaki weed	Amaranthaceae
Ammania baccifera	Redstem	Lythraceae
Caesulia axillaris	Pink node flower	Asteraceae
Cleome viscosa	Cleome	Capparaceae
Commelina benghalensis	Wandering jaw	Commepinacea
Commelina communis	Day flower	Commepinacea
Cyanotis axillaris	Creeping cradle	Commepinacea
Digera arvensis	Digerakondra	Amaranthaceae

Source: (Singh *et al*., 2016) [56-60]

Weed Category 3: Some of the common sedges weed of DSR

Scientific name	Common name	Family
Fimbristylis miliacea	Globefingerush	Cyperaceae
Cyperus difformis	Small flower umbrella sedge	Cyperaceae
Cyperus iria	Flat sedge	Cyperaceae
Cyperus rotundus	Purple nutsedge	Cyperaceae

Source: (Singh *et al*., 2016) [56-60]

(A) Cultural Approach
Cultural methods play an important role in reducing crop-weed competition by several techniques, which are described below in brief,

i) Seed Rate
Keeping seed rate high, spacing narrow favors good seed quality, higher productivity suppresses weed population. A seeding rate of 95-125 kg/ha for inbred varieties and 83-92 kg/ha for hybrid varieties is needed to acquire maximum yields in competition with weeds (Chauhan *et al*., 2011) [62-70].

ii) Stale Seed Bed
In this technique, by irrigating the field one or two times 2-4 weeks prior to sowing, for allowing weeds to germinate and grow and then these weeds are killed by either a nonselective herbicide or by shallow tillage operation. According to Bista, by 2018 [64] this technique helps in suppressing the weed population up to 53%. Application of glyphosate or paraquat as a non-selective herbicide, here applying glyphosate @1 Kg per hectare found more effective and helps in achieving higher yield and B:C ratio in compare to stale seedbed technique using shallow tillage (M. Singh, 2013) [63]. Thus this technique brings out a higher number of grain per yields, high harvest index, suppression of weeds up to 53%.

iii) Brown Manuring with Sesbania/Sesbania co-culture
Growing Sesbania (legume) with rice as a green manure, either as rice or mixed crop or an intercrop is known as brown manuring (sesbania co-culture). Seed rate of Sesbania should be 25 kg per hectare, well adjusted with rice. 25-30 days after sowing (DAS), 25-30 days after sowing (DAS), Sesbania is killed with 2,4-D ester @ 0.5 kg per hectare (Bista, 2018) [64], when Sesbania is 30-40 cm tall (Raj and Syriac, 2017) [65].
Right timing for showing of Sesbania is on the sowing day of rice, for weed suppression, as it can bring down half the weed population, without harming main crop rice. Brown manuring with Sesbania proved to be more effective against broadleaf weed and sedges but lesser on grasses. So, Pendimethalin is recommended for use as pre-emergence in order to suppress grass weed population. Best timing for Sesbania incorporation is at 30 DAS for semi dry rice and also one can use 2,4-D @1 kg per hectare for taking down Sesbania (Anitha, S. and Mathew, nd). Also, Sesbania co-culture is beneficial for nitrogen fixation, as it enhances nitrogen availability in soil and is proficient in solving the soil crust formation problem.

iv) Cover Crop and Residue Mulch
Cover crops used for preventing soil from erosion, maintains soil moisture, for pest and weed management, attracting pollinators, used for mulching, source of green manure and of organic matter and many more (Nautiyal *et al*., 2017) [42]. And crop residues are known to have a chemical (allelopathic), also a physical effect on the growth of subsequent crops and weeds (Purvis *et al*., 1985) [67], acting as a physical barrier for the turning up of weeds.
According to (Singh *et al*., 2007) [68], it was found that wheat residue mulch @ 4 ton/ha, when used decreases the emergence of grass weeds by 44-47%, broadleaf weeds by 56-72% in dry-drill-seeded rice. Using high amounts of residue in the field causes delay in weed emergence, because it acts as a physical barrier in a way of light penetration into the soil for weed growth and development.

v) Soil Solarization
Soil solarisation not only kills weeds, also it brings down the pest population, here the weed-clean field is covered with a transparent airproof substance to accumulate solar energy, in a purpose of raising soil temp. upto lethal level for suppressing many seeds before emergence and killing of soil borne pathogens. This technique can be used effectively in hot areas, where availability of sunlight is in abundance.
Not only suppressing weed population, this technique has other benefits too such as helps in improving soil structure, increasing nitrogen concentration with other essential plant nutrients, control of soil borne insects and pest population. It works by raising soil temperature at least 42-55 °C for sufficient duration (several weeks) as duration required depends upon air temperature and also the amount of solar

radiation, whereas the temperature of soil at 5 cm under mulch rises by 10-15 °C and 10-12 °C at 10 cm depth.

B) Mechanical Approach
i) Manual Hand Weeding
Removal of weeds manually by using a hand or small hand tool is a traditional farmers practice for controlling weed infestation in rice but in present time it is disappointing to opt for manual hand weeding in DSR because of labor shortage, high charges demanded by workers, time consuming, high drudgery. It is estimated that around 150-200 labor-days per hectare are quiet in order to keep the rice field weed free. Weedy panicles of rice are cut by using a machete or a special knife attached to a stick.

ii) Mechanical Weeders and Other Implements for Inter-Cultivation
Mechanical weeders are used for uprooting weeds, which are in between rows but not for weeds which are within the rows. During weeding, sufficient soil moisture is required for increasing efficiency of weeder. From hand pushed cono-weeder, farmers incline towards power weeder, which is petrol/diesel operated as its time saving, easy to operate effective one and also reduces dependency on herbicides.
Thus, it is necessary to develop more and more new implements or tools which favors and promotes mechanical methods for controlling weeds in the field because these are eco-friendly practices, and do not harm nature. Efforts should be done in this field by educating and awaring farmers for the adoption of mechanical methods; new techniques should be invented which promote this eco-friendly approach of weed management.

C) Biological Approach
Biological approach for controlling weed in DSR technique is an eco-friendly practice which reduces heavy side dependency, while it is recommended that in DSR not to solely depend on this because of high weed pressure.
In aerobic rice, where there is no standing water in the field, herbivorous bio-agents such as fish, tadpoles, shrimp ducks, and pigs are unable to control weed infestation. In the DSR cultivation system, use of microp-herbicide reduces herbicidal dependency. Fungi used as biocontrol agents for barnyard grass are *Exserohilum monicrus* and *Cochliobolus lunatus*. So controlling *Leptochloa chinensis* use of *Setosphaeria* sp. *C. rostrata* is beneficial. Whereas, Collego, a powder formulation of *Colletotrichum gloeosporioides* (Penz.) and Sacc.f.sp aeschynomene, applicable for the control of northern jointvetch (*Aeschynomene virginica* (L.) B.S.P) in the rice fields.

D) Chemical Approach
Mostly, farmers prefer use of chemical herbicide over manual and mechanical methods because of low labor requirement, low labor cost, low input cost, most effective, time and energy saving approach for managing weed infestation in rice. Nowadays, use of herbicides is considered an immense contributor to agriculture for weed control. Herbicides may be considered as a viable alternative to hand weeding (Chauhan and Johnson, 2011; Anwar *et al*., 2012a) [62-69, 75]. Time of application, method of application, selection of herbicide are some factors which one should have to keep in mind before applying chemical herbicides in rice fields for controlling weed infestation. Table 4, display list of herbicides recommended for controlling weed population.

Table 4: Recommended Chemical Herbicides in DSR system

(i) Post-Emergence Herbicides			
Herbicides (Trade Name)	**Dose (g/ha)**	**Application Stage**	**Weed Control**
Pendimethalin 30 EC	1000-1500	0-3 DAS	Annual with BLWs control.
Pretilachlor 30.7% EW	450-600	0-3 DAS	Grassy weed under puddle conditions
Oxadiargyl 16 EC	90	0-3 DAS	Grasses and sedges but BLWs control is not satisfying as required.
Oxyfluorfen 23.5 EC	150-240	0-6 DAS	Can control grasses, sedges and BLWs.
Anilofos 30	400	3-5 DAS	Annual grasses and some BLWs.
Oxadiazon 25 EC	500-750	Pre-emergence or early post emergence.	Control broad spectrum of weeds.
(ii) Post- Emergence Herbicides			
Cyhalofop- butyl-10 EC	75-80	15-20 DAS	Annual grasses but particularly barnyard grass and Leptochloa.
Bispyribac-sodium 10 SC	20	15-20 DAS	Annual grasses, some BLWs and some sedges.
Chlorimuron-ethyl+Metsulfuron Methyl 20 WP	4	15-20 DAS	Broad spectrum weeds, including BLWs and grasses.
2,4-D 38 EC, 34 EF, 80 WP	750-1000	20-25 DAS	Sedges and BLWs. Drain before application of herbicide reflooded again for a few days. Effective against water hyacinth and Monochoria.
Ethoxysulfuron 15% WDG	12.5-15	15-20 DAS	Broad leaves and sedge.

Source: (Singh *et al*., 2016) [56-60]

Integrated Weed Management (IWM)
Weed infestation under aerobic rise is economically unprofitable, as it decreases crop yield. For controlling the weed population, we have several methods which include physical, cultural, biological and chemical approaches. By adopting a single control measure, farmers cannot acquire desirable outcomes, whereas several research studies have emphasized that integration of various components in a logical succession might wind up with acceptable outcomes in weed management (Papnai *et al*., 2017) [47]. Land and soil condition, water availability, infestation of which weed species in that area, resources availability are various factors which decides operations that must be there in IWM. IWM promotes sustainability and is an eco friendly approach, also it minimizes production cost under DSR rise production. Effective IWM integrates 'little harmer technology' instead of a single 'large harmer' method to control the weed of a wide range (Kumar and Ladha, 2011) [23].

Precise Water Use Efficiency
Around 72-80% of freshwater is utilized in agriculture, out of that rice cultivation accounts for 85%. This can cause fresh water scarcity worldwide in upcoming recent years. Production of rice by exercising conventional transplanting method consumes 3000-5000 liters of water; only two produce 1 kg rice. On the other hand, the DSR method is one

such substantial water-saving technology for rice establishment, in which once 150 mm rain or irrigation water has accumulated, whereas TPR demands 450 mm of water. By reducing water losses caused by seepage, evaporation and percolation, DSR increases the water use efficiency and also by laser land leveling, crack ploughing lowering the water bypass flow. Bund management also plays an essential role for maintaining water depth uniform and also brings down water losses via seepage and leakage (Humphreys *et al*., 2010) [70].

In India many research institutes/ universities came forward in order to take initiative for developing varieties which are highly water efficient and suitable in the DSR system. ICAR-NRRI, also involved in aerobic rice research and released 9 aerobic water efficient varieties of rice by releasing through Central Sub Committee on seed standards, Notification and Release (CVRC) and State Variety Release Committee (SVRC). Anagha (ARB6) MAS26 and MAS 946-1 are three aerobic rice varieties released from the University Of Agriculture science (UAS), GKVK, Bangalore for Karnataka, these varieties are appropriate for aerobic rice cultivation having high water use efficiency with potential of drought tolerance. Irrigation needed at the intervals of 5-7 days, which can be skipped at the time of rainfall. 7.0 t/ha in station trials at UAS, Bangalore is the yield obtained by these genotype lines, and around 3-5 t/ha yield was recorded in farmer's field (Shashidhar, 2012) [78].

From sowing to emergence, it is necessary to maintain moisture and avoid rotting, soil should not be saturated. After showing in dry soil, farmers have to apply a flush irrigation to wet the soil, if it is unlikely to rain followed by saturating the field at the three leaf stage (Bouman *et al*., 2007) [72]. In accordance with research study of (Gupta *et al*., 2006) [73] it is recommended to avoid water stress and maintain soil moisture by keeping soil wet at tillering, panicle initiation and grain filling stage. Anthesis time water stress results in maximum panicle sterility. Water management schedule with required number of irrigation at different phenological stages in DSR, which saves 33-53% irrigation water.

S. No.	Phenological stages	No. Of irrigation (times)
1.	Pre sowing	1
2.	Emergence of seedling (7-10 days)	1
3.	Tillering (30-45 DAS)	1
4.	Panicle initiation to grain filling	1

Source: (Joshi *et al*., 2013) [35]

Pest and Disease Management

Approx. 18% to 16% reduction in yield is reported every year globally due to infestation of pest (non-virus) pathogens in the absence of any physical, chemical or biological pest control method (Oerke 2006) [74]. Greater efforts can be made by the adoption of sustainable and ecological approaches for managing pest populations in order to obtain benefits from the DSR system. In the lowland rice cultivation environment, it is revealed that the injury profiles were dominated by stem rot and sheath blight; bacterial leaf blight, plant hoppers and leaf folder; and sheath rot, brown spot, leaf blast and neck blast (Savary *et al*., 2000) [75]. Population of apple snails and rats causes complications in crop establishment under the DSR system. Arthropod insect pests, yellow orange leaf virus, ragged stunt virus, plant hoppers, fungus *Gaeumannomyces graminis* var. Gramines, *Meloidogyne graminicola* (MG), root-knot nematodes are among insect-pest which cause nuisance in DSR rice fields and may cause crop failure up to 100 percent. In consonance with Kukal and Aggarwal, 2002 [76], root knot nematodes (RKN's) were found to be the most damaging pathogen for aerobic rice.

It is mandatory for growers to take precautions in time for minimizing the outbreak of insects, pests and diseases in rice fields. Use of resistant crop varieties for cultivation, deep summer ploughing, maintaining weed free field condition, applying organic fertilizer are some of the prerequisites for efficient management of viral disease/pests and furthermore enhance rice plant growth and development. Soaking the cow dung balls in kerosene and fumigating them near burrows of burrowing animals ensures better control over rats and other borrowing pests populations in the field. Neem *(Azadirachta indica Juss)* and neem products act as fungicides, insecticides, nematicides and consist of antiviral properties (Prasad, 2007) [77]. Heating soil at 120 °C temperature is enough for controlling soil pathogens. Application of nitrogenous fertilizer at optimum rate helps in protecting fields from brown plant hopper and blast attack. Effect of nematicide and biocides on the grain yield was studied (Kreye *et al*., 20009b) [78] with a conclusion that the grain yield was maximum after treating crops with biocide (nemagel or dazimer @50 ga.im-2). Use of bio agents like trichoderma harzianum @ 4ga per hectare and trichoderma virens @ 8g per hectare in soil after nematode infestation results in better control and gaining optimum yield under DSR field within a week.

Conclusion

Establishment of rice through transplanting seedlings from nursery to puddled field requires huge amounts of water, labor. TPR deteriorates soil properties physically and chemically which provides an obstacle for gaining potential yield of crops in the rice-wheat cropping system. Also, TPR contributes a major role in methane gas emission (~48% of the greenhouse gasses emitted by agricultural sectors). Within all of these TPR demands more drudgery, time and cost than a DSR system. Comparing TSR with DSR, DSR is cost and time effective. DSR can be a resource-efficient, viable, feasible, economical, eco-friendly, climate resilient and sustainable alternative to TPR. Inclination towards conservation agriculture (CA) is a present need for future securement, in the field of agriculture. Hence, shift from TPR to DSR is due to water scarcity and expensive labor (Chan and Nor, 1993) [12]. Weed infestation, poor stand crop, lack of mechanization, precise application of inputs and less knowledge of DSR among farmers are the major hindrances for the adoption of the DSR system.

Taking consideration of environmental health, use of herbicide should be avoided. Integration of weed management practices should be based on climatic conditions. Technologies like stale seed bed, mulching, soil solarisation, crop rotation, land leveling, sesbania-coculture, short-duration cultivars, raised bed planting, irrigation scheduling based on soil matric potential (SMP), use of resistant varieties priming our helpful in solving problem of wheat infestation, poor crop stand, pest and disease outbreaks.

Research on DSR regarding site specific production technologies, effective weed and resource management methods, genetic and varietal advancement and yield improvement should be made. Extension activities must be carried out for the awareness of DSR techniques among farmers.

References

1. Ministry of Agriculture & Farmers Welfare. Second Advance Estimates of Production of Major Crops for 2021-22 Released; 2022, Feb 16. https://pib.gov.in/PressReleasePage.aspx?PRID=179883.
2. Rutledge K, McDaniel M, Teng Santani, Hall H, Ramroop T, Sprout E, *et al*. Food Staple; 2022, May 20. https://education.nationalgeographic.org/resource/food-staple.
3. Bandumula N. Rice Production in Asia: Key to Global Food Security. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences. Springer Nature Publishers. 2018;88(4):1323-1328. DOI:10.1007/s40011-017-0867-7. http://krishi.icar.gov.in/jspui/handle/123456789/31554.
4. Shahbandeh M. Leading countries based on the producer of milled rice in 2020/2021 reported in statista; c2022, July 27. https://www.statista.com/statistics/255945/top-countries-of-destination-for-us-rice-exports-2011/.
5. Shahbandeh M. Principal rice exporting countries worldwide 2021/2022 reported in statista; 2022, July 27. https://www.statista.com/statistics/255947/top-rice-exporting-countries-worldwide-2011/.
6. Bindu H. Punjab's Water crisis Due to Paddy Cultivation. Grainmart; c2021. https://www.google.com/amp/s/www.grainmart.in/news/punjabs-water-crisis-due-to-paddy-cultivation/amp/.
7. Barker R, Dawe D, Tuong TP, Bhuiyan SI, Guerra LC. The outlook for water resources in the year 2020: Challenges for research on water management in rice production. In: Assessment and Orientation. Towards the 21st Century, Proceedings of 19thSession of the International Rice Commission, 7–9 September 1998, Cairo, Egypt. Food and Agricultural Organization, Rome; c1998. p. 96-109.
8. Chaba AA, Dampdaran H. The COVID nudge: Labour shortage makes Punjab, Haryana farmers switch from paddy to cotton. The Indian Express; c2022. https://www.google.com/amp/s/indianexpress.com/article/india/covid-19-punjab-haryana-farmers-paddy-cotton-6385600/lite/.
9. Duxbury JM, Abrol IP, Gupta RK, Bronson KF. Analysis of long-term fertility experiments with rice-wheat rotation in South Asia. In I.P. Abrol, K.F.Bronson, J.M. Duxbury, and R.K. Gupta (eds.), Long-term soil fertility experiments in rice-wheat cropping systems. Rice-wheat Consortium Paper Series 6. New Delhi, India: RWC; c2000. p. 7-22.
10. Tribune News Service. Amritsar agriculture officials encourage farmers to use DSar tech. Tribune India; 2022, June 17. https://www.google.com/amp/s/m.tribuneindia.com/news/amritsar/amritsar-agriculture-officials-encourage-farmers-to-use-dsr-tech-404583.
11. Pandey S, Velasco L. Economics of direct seeding in Asia: patterns of adoption and research priorities. In: Pandey, S., Mortimer, M., Wade, L., Tuong, T.P., Lopes, K., Hardy, B. (eds.). Direct Seeding: Research Strategies and Opportunities. International Rice Research Institute, Los Banos Philippines; c2002.
12. Chan CC, Nor MAM. Impacts and implications of direct seeding on irrigation requirements and systems management. In: Paper presented at the workshop on water and direct seeding for rice, 14-16 June, 1993, Muda Agricultural development Authority, Ampang Jajar, Alor Setar, Malaysia; c1993.
13. Pepsico International. Direct seeding of paddy-the work of pepsico reported in India water portal; c2011. http://www.indiawaterportal.org/post/6754.
14. Sarkar RK, Das S. Yield of rainfed lowland rice with medium water depth under anaerobic direct seeding and transplanting. Tropical Science. 2003 Dec;43(4):192-198.
15. Sachan VK, Kumar R, Nautiyal P. Impact of hydropriming treatments on seed invigoration in vegetable pea (*Pisum sativum* L.), Vegetable Science. 2016;43(1):70-72.
16. Singh N, Singh B, Rai AB, Dubey AK, Rai Ashok. Impact of Direct Seeded Rice (DSR) For Resource Conservation. Indian Research Journal of Extension Education, (Special Issue). 2012;2:6-9.
17. Pathak H, Sankhyan S, Dubey DS, Bhatia A, Jain N. Dry direct-seeding of rice for mitigating greenhouse gas emission: field experimentation and simulation. Paddy and Water Environment. 2013 Jan;11:593-601.
18. Grigg DB. The agricultural systems of the world: an evolutionary approach. Cambridge University Press; 1974 Nov 7.
19. Pandey S, Velasco L. Trends in crop establishment methods in Asia and research issues. In: Toriyama K, Heong KL, Hardy B (ed) Rice Is Life: Scientific Perspectives for the 21st Century. International Rice Research Institute, Los Baños, Philippines and Japan International Research Center for Agricultural Sciences, Tsukuba, Japan; c2005. p. 178-181.
20. Rao AN, Nagamani A. Available technologies and future research challenges for managing weeds in dry-seeded rice in India. Proceed of the 21st Asian Pacific Weed Sci Soc Conference, 2–6 October 2007, Colombo, Sri Lanka, 391-491.
21. Bhushan L, Ladha JK, Gupta RK, Singh S, Tirol-Padre A, Saharawat YS, *et al*. Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. Agronomy Journal. 2007 Sep;99(5):1288-96.
22. Rao AN, Johnson DE, Sivaprasad B, Ladha JK, Mortimer AM. Weed management in direct-seeded rice. Advances in agronomy. 2007 Jan 1;93:153-255.
23. Kumar V, Ladha JK. Direct seeding of rice: recent developments and future research needs. Advances in agronomy. 2011 Jan 1;111:297-413.
24. Khan MAH, Alam MM, Hossain MI, Rashid MH, Mollah MIU, Quddus MA, *et al*. Validation and delivery of improved technologies in the rice-wheat ecosystem in Bangladesh. In Integrated Crop and Resource Management in the Rice–Wheat System of South Asia" (J. Ladha, Y. Singh, O. Erenstein, and B. Hardy, Eds.), International Rice Research Institute, Los Banos, Philippines; c2009. p. 197-220.
25. Balasubramanian V, Hill JE. Direct seeding of rice in Asia: Emerging issues and strategic research needs for the 21st century. In Direct Seeding: Research Strategies and Opportunities (S. Pandey, M. Mortimer, L. Wade, T. P. Tuong, K. Lopez, and B. Hardy, Eds.), International

Rice Research Institute, Los Banos, Philippines; c2002 p. 15-39.
26. Jaafar MH, Amit DR, Tulas MT. Wet-seeded rice in Sabah (Malaysia). In Constraints, Opportunities and Innovations for Wet-Seeded Rice (K. Moody, Ed.),IRRI Discussion Paper Series No. International Rice Research Institute,Los Banos, Philippines. 1995;10:63-72.
27. Azmi M, Johnson DE. Crop establishment options for lowland irrigated rice in relation to weed infestation and grain yield. J. Trop. Agric. Food Sci. 2009;37:111-117.
28. Nguyen NV, Ferrero A. Meeting the challenges of global rice production. Paddy Water Environ. 2006;4:1-9.
29. Pandey S, Velasco LE. Economics of alternative rice establishment methods in Asia: a strategic analysis. Social Sciences Division Discussion Paper, International Rice Research Institute, Los Banos, Philippines. 1999;1(1):12-8.
30. Fischer AJ, Antigua G. Weed management for rice in Latin America and the Caribbean. In: Auld BA, Kim KU (eds) Weed management in rice, Plant production and protection paper. FAO, Rome. 1996;139:159-179.
31. Tripathi RP. Water management in rice-wheat system. In: Pandey, R.K., Dwivedi, B.S., Sharm, A.K. (Eds.),Rice-Wheat Cropping System. Project directorate for Cropping Systems Research, Modipuram, India; c1996. p. 134-147.
32. Kahlown MA, Gill MA, Ashraf M. Evaluation of Resource Conservation Technologies in Rice-Wheat System of Pakistan. Pakistan Council of Research in Water Resources (PCRWR), Research Report-1, PCRWR, Islamabad, Pakistan; c2002.
33. Dahiphale AV, Singh UP, Kumar S, Singh H, Kashyap SK. Dry direct seeded rice: A potential resource conservation technology for sustainable rice production: A review. Journal of Pharmacognosy and Phytochemistry. 2017;6(6):1497-1501.
34. Joshi E, Kumar D, Lal B, Nepalia V, Gautam P, Vyas AK. Management of direct seeded rice for enhanced resource-use efficiency. Plant Knowledge Journal, 2013;2(3):119.
35. Gill MS, Kumar A, Kumar P. Growth and yield of rice (*Oryza sativa*) cultivars under various methods and times of sowing. Indian Journal of Agronomy. 2006;51(2):123-7.
36. Chandra D, Moorthy BT, Jha KP, Mannna GB. Agronomic practices for augmenting rice (*Oryza sativa*) production in rainfed upland ecosystem of Orissa. Indian J Agron. 1991;36(3):313-21.
37. Narayanaswamy S, Yoogeshwar RY, Ramsheshaiash K, Sivasankaan RV. Effect of time and method of sowing rice varieties in puddled soil during wet season. Oryza. 1982;19:47-52.
38. Bhullar MS, Kumar S, Kaur S, Kaur T, Singh J, Yadav R, *et al*. Management of complex weed flora in dry-seeded rice. Crop Protection. 2016 May 1;83:20-6.
39. Kakraliya SK, Singh LK, Yadav AK, Jat HS, Kakraliya SS, Choudhary KM, *et al*. Smart package and practices for direct seeded rice (DSR). Innovative Farming. 2016 May 18;1(2):49-55. 25.
40. Moody K. Weed control in multiple cropping. “Cropping Systems Research and Development for the Asian Rice Farmer”, International Rice Research Institute, Los Baños Laguna, Philippines; c1977. p. 281-293.
41. Nautiyal P, Sachan VK, Papnai G, Tiwari RK, Manisha. Improving growth, yeild and profitability in apple through mulching in rainfed condition in hilly region of Uttarakhand. Journal of Krishi Vigyan. 2017;6(1):101-104
42. Kumawat A, Sepat S, Vishwakarma AK, Kumar D, Wanjari RH, Sharma NK, *et al*. Management practices for enhancing resource use efficiency under direct seeded rice-A review. Journal of Pharmacognosy and Phytochemistry. 2019;8(2S):916-922.
43. Dhillon BS. Direct seeded rice: Opportunities and challenges. Biotic and Abiotic Stress Tolerance in Plants under Changing Climatic Conditions.
44. Reddy AK, Prudhvi N, Mehta CM. Direct seeded rice-future of rice (*Oryza sativa*) cultivation. International Journal of Research and Analytical Reviews. 2020;7(4):279-291.
45. Pantuwan G, Fukai S, Cooper M, Rajatasereekul S, Toole JC. Yield response of rice (*Oryza sativa* L.) genotypes to different types of drought under rainfed lowlands. Plant factors contributing to drought resistance. Field Crops Res. 2002;73:181-200.
46. Papnai G, Sachan VK, Nautiyal P, Manisha. Performance of Front line demonstartion in hilly region of Uttarakhand. 2017;30(2):286-289.
47. Joshi R. Management interventions to enhance water productivity in dry-seeded rice (*Oryza sativa* L.). International Journal of Agriculture, Environment and Biotechnology. 2016;9(1):69-83.
48. Rehman H, Kamran M, Basra SM, Afzal I, Farooq M. Influence of seed priming on performance and water productivity of direct seeded rice in alternating wetting and drying. Rice Science. 2015 Jul 1;22(4):189-196.
49. Kashiwar SR, Kumar D, Dongarwar UR, Mondal B, Nath T. Experiences, challenges and Opportunities of Direct Seeded Rice in Bhandara District of Maharashtra. Journal of Energy Research and Environmental Technology. 2016;2(3):141-145.
50. Bhatt R, Kukal SS. Direct seeded rice in South Asia. In sustainable agriculture reviews. Springer, Cham; c2015. p. 217-252.
51. Buta Singh Dhillon, Kumar Virender, Sagwal Pardeep, Kaur Navjyot, Gurjit Singh Mangat, *et al*. Agronomy; Basel. 2021;11(5):849.
52. Adhikary S, Biswas B, Chakraborty D, Timsina J. Seed priming with selenium and zinc nanoparticles modifies germination, growth and yield of direct seed rice (*Oryza sativa* L.) In: Scientific Reports. 2022;12(1):7103. DOI: 10.1038/s41598-022-11307-4.
53. Gopal R, Jat RK, Malik RK, Kumar V, Alam MM, Jat ML, *et al*. Direct Dry Seeded Rice Production Technology and Weed Management in Rice Based Systems. Technical Bulletin. International Maize and Wheat Improvement Center, New Delhi, India, 2010, 28.
54. Manes GS, Dixit A, Singh A, Mahal JS, Mahajan G. Feasibility of mechanical transplanter for paddy transplanting in Punjab. Agric Mech Asia Africa Latin Am. 2013 Jun 1;44:14-17.
55. Kamboj BR, Kumar A, Bishnoi DK, Singla K, Kumar V, Jat ML, *et al*. Direct Seeded Rice Technology in Western Indo-Gangetic Plains of India: CSISA Experiences. CSISA, IRRI and CIMMYT; c2012. p. 16.
56. Singh VP, Singh SP, Dhyani VC, Banga A, Kumar A, Satyawali K, *et al*. Weed management in direct-seeded

rice; c2016.
57. Caton BP, Cope AE, Mortimer M. Growth traits of diverse rice cultivars under severe competition: implications for screening for competitiveness. Field Crops Research. 2003 Aug 20;83(2):157-172. https://doi.org/10.1016/S0378-4290(03)00072-8
58. Hasanuzzaman M, Ali MH, Alam MM, Akther M, Alam KF. Evaluation of pre-emergence herbicide and hand weeding on the weed control efficiency and performance of transplanted Aus rice. American-Eurasian Journal of Agronomy. 2009;2(3):138-143.
59. Sen S, Ghosh A, Mondal D, Sadhukhan R, Roy D, Paul K. Herbicide options for cost-effective weed control and sustainable rice production in direct-seeded rice.
60. Singh V, Singh S, Dhyani V, Banga A, Kumar A, Satyawali K, *et al*. Weed management in direct-seeded rice. Indian Journal of WeedScience. 2016;48:233. https://doi.org/10.5958/0974-8164.2016.00059.9.
61. Chauhan BS, Singh VP, Kumar A, Johnson DE. Relations of rice seeding rates to crop and weed growth in aerobic rice. Field Crops Research. 2011 Feb 28;121(1):105-115. https://doi.org/10.3126/ijasbt.v6i3.21174
62. Singh M. Competitiveness of rice cultivars under stale seedbed in dry direct-seeded rice. Indian Journal of Weed Science. 2013;45:171-174.
63. Bista B. Direct Seeded Rice: A New Technology for Enhanced Resource-Use Efficiency. International Journal of Applied Sciences and Biotechnology. 2018;6(3):181-198. https://doi.org/10.3126/ijasbt.v6i3.21174
64. Raj SK, Syriac EK. Weed management in direct seeded rice: A review. Agricultural Research Communication Centre. 2017;38(1):41-50. https://doi.org/10.18805/ag.v0iOF.7307
65. Anitha S, Mathew J. (n.d.). In situ green manuring with dhaincha (Sesbania aculeata Pers.): A cost-effective management alternative for wet seeded rice (*Oryza sativa* L.). Journal of Tropical Agriculture. 2010 Dec 27;48(2):34-39
66. Purvis CE, *et al*. Selective regulation of germination and growth of annual weeds by crop residues. Weed Res. 1985;25(6):415-421.
67. Singh S, Ladha JK, Gupta RK, Bhushan L, Rao AN, Sivaprasad B, *et al*. Evaluation of mulching, intercropping with Sesbania and herbicide use for weed management in dry-seeded rice (*Oryza sativa* L.). Crop Protection. 2007 Apr 1;26(4):518-24. https://doi.org/https://doi.org/10.1016/j.cropro.2006.04.024.
68. Chauhan BS, Johnson DE. Growth response of direct-seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. Weed Science. 2011 Mar;59(1):119-122.
69. Anwar MP, Juraimi AS, Puteh A, Man A, Rahman MM. Efficacy, phytotoxicity and economics of different herbicides in aerobic rice. Acta Agriculturae Scandinavica, Section B–Soil & Plant Science. 2012a Oct 1;62(7):604-615.
70. Humphreys E, Kukal SS, Christen EW, Hira GS, Sharma RK. Halting the groundwater decline in north-west India—which crop technologies will be winners?. Advances in agronomy. 2010 Jan 1;109:155-217.
71. Shashidhar HE. An eco-friendly aerobic rice BI 33 (Anagha); c2012. Available at www. aerobic rice. in.
72. Bouman BAM, Lampayan RM, Tuong TP. Water Management in Irrigated Rice: Coping with Water Scarcity. International Rice Research Institute, Los Banos, Philippines, 2007, 54.
73. Gupta RK, Ladha JK, Singh S, Singh R, Jat ML, Saharawat Y, *et al*. Production technology for direct seeded rice. Technical Bulletin Series. 2006;8:14.
74. Oerke EC. Crop losses to pests. J Agric Sci. 2006;144:31-43.
75. Savary S, Willocquet L, Elazegui FA, Teng PS, Van Du P, Zhu D, *et al*. Rice pest constraints in tropical Asia: characterization of injury profiles in relation to production situations. Plant Disease. 2000 Mar;84(3):341-356.
76. Kukal SS, Aggarwal GC. Percolation losses of water in relation to puddling intensity and depth in a sandy loam rice (Oryza sativa) field. Agricultural Water Management. 2002 Sep 30;57(1):49-59.
77. Prasad R. Phosphorus management in the rice-wheat cropping system of the Indo-Gangetic plains. Better Crops-India. 2007;1(1):8-11.
78. Kreye C, Bouman BA, Reversat G, Fernandez L, Cruz CV, Elazegui F, *et al*. Biotic and abiotic causes of yield failure in tropical aerobic rice. Field Crops Research. 2009 Apr 30;112(1):97-106.