Review Article

Direct-seeded rice: potential benefits, constraints and prospective – A Review

Abstract

The production of direct seeded rice (DSR) has become a viable substitute for conventional transplanting techniques, providing several benefits such as decreased greenhouse gas emissions, labor and water savings, and improved resource efficiency. With a focus on the agronomic, economic, and environmental aspects of DSR cultivation, this abstract offers a thorough summary of the field's current situation. The main ideas and techniques of DSR cultivation are covered in this study, including weed control, seed selection, land preparation, sowing techniques, and nutrient application examines current scientific findings and technical developments targeted at improving DSR systems, such as the creation of stress tolerant, high yielding rice varieties appropriate for direct seeding, precision seeding tools, and integrated weed control plans. The environmental effects of DSR cultivation are investigated and found worthy in several ways like its contributions to water conservation, improving soil health, and reducing greenhouse gas emissions, in addition to its agronomic and financial advantages. The review cited in various literature itemized that the difficulties and barriers to the implementation of DSR includes technological constraints, gaps in farmer knowledge and expertise, and socioeconomic issues. The significance of research, extension services, policy support, and farmer capacity building programs is emphasized in the strategies for removing these obstacles and encouraging the broad adoption of DSR practices. With implications for food security, resource conservation, and rural livelihoods, this abstract offers insightful information about the possibility of direct seeded rice growing as a sustainable, effective, and environment friendly method of producing rice.

Keywords- DSR, Environmental sustainability, Economic, Food security

Introduction

Rice is an important source of food for more than half of the world population. About 90% of the total rice is grown and consumed in Asia. The term 'rice is life' is most appropriate for India as this crop plays vital role in country's food security and is the backbone of livelihood for millions of rural households (Pathak *et al.*, 2011). Being the major source of food after wheat, it meets 43 % of calorie requirement of more than two third of the Indian population (Kaur and Singh, 2017). Sustainable agricultural practices involve the successful management of resource for agriculture to satisfy changing human need while maintaining the quality of the environment and conserving natural resources. In case of rice the long-term sustainability of this flooded system is threatened by the rapid changes in climatic events causing erratic rainfall and abiotic stresses, looming water and energy crisis, low nitrogen use efficiency, increasing micronutrient deficiencies, increasing labor costs and reduced labor availability, increased methane emissions, yield stagnation, and the negative effects of rice crops on post- rice crops (Nawaz *et al.*, 2022). Increasing water scarcity, water loving nature of rice cultivation and increasing labour wages triggers the search for such alternative crop establishment methods which can increase water productivity. Direct seeded rice (DSR) is the only viable option to reduce the unproductive water flows. It has been recognized as the principal method of rice establishment since 1950's in developing countries (Kaur and Singh 2017). To overcome such a situation, ways must be found to reduce water requirements and increase productivity of rice (Mahapatra *et al.*, 2021). The lowering water table, scarcity of labour during peak periods, deteriorating soil health demands some of the major problems that seek alternative establishment method to sustain productivity of rice as well as natural resources. Direct seeded rice (DSR) is gaining popularity and is a feasible alternative to conventional puddled transplanted rice because of its low-input demand. It offers certain advantages *viz*., it saves labour, requires less water, better adaptation to climatic risks, less drudgery, early crop maturity, low production cost, better soil physical conditions for succeeding crops and less methane emanation, provides better option to be the best fit in different cropping systems and a very exciting opportunity to improve water and environmental sustainability. At present, the Indian farmers are slowly adopting the DDSR (Dry Direct Seeded Rice) and they are broadcasting dry seeds by manually or by tillage equipment in well-pulverised soil (Tyagi *et al.,* 2020). In a study Tripathi *et al.* (2014) concluded that farmers preferred to adopt direct seeding in rice cultivation due to high labour requirement in TPR method. DSR requires less labour and provides more economical gain in rice cultivation. Comparative yields in DSR can be obtained by adopting various cultural practices *viz*. selection of suitable cultivars, proper sowing time, optimum seed rate, proper weed and water management (Kaur and Singh 2017). The development of short duration, early maturing cultivars and efficient nutrient management techniques along with increased adoption of integrated weed management methods have encouraged many farmers to switch from transplanted to DSR culture (Joshi *et al*., 2013).

Direct Seeded Rice and its establishment method:

Direct seeding of rice is the process of growing rice crop in the field by sowing of seeds in the field rather than by transplanting seedlings from the nursery. Once germination and seedling establishment are complete, the crop can then be sequentially flooded and water regimes maintained as for transplanted rice. Alternatively, the crop can remain rainfed, the upper surface soil layers fluctuating from aerobic to non-aerobic conditions (Bista 2018).

Method of Establishing Direct Seeded Rice (DSR): There are three principles method of establishing direct seeded rice.

1. Dry seeding: Dry seeds are sown in dry and mostly aerobic soil. It can be established using several different methods, including a) Broadcasting of dry seeds on unpuddled soil after either ZT or CT b) Dibbled method in a well-prepared field and c) Drilling of seeds in rows after CT, minimum tillage (MT), zero tillage (ZT) using a power tiller operated seeder (Joshi *et al.*, 2013)**.**

2. **Wet seeding:** Wet-DSR involves sowing of pre- germinated seeds (radicle 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. When pre germinated seeds are sown / drilled into puddled soil, the seed environment is mostly anaerobic and this is called as anaerobic Wet-DSR. Wet-DSR under aerobic and anaerobic, seeds can either be broadcasted or sown in-line using a drum seeder or an anaerobic seeder with a furrow opener and closer. Suitable ecology is rainfed lowlands and irrigated areas with good drainage facility.

3. **Water seeding:** In this method pre germinated seeds sown in standing water. Broadcasting on standing water of 5-10 cm **(Joshi *et al.*, 2013)**. It is practided In irrigated areas with good landlevelling and in areas with red rice problem **(Farooq *et al.*, 2011)**

Comparison between DSR and TPR

Grorth:

Taller plant, more dry matter accumulation and increased number of tillers per meter square can be produced under direct seeded rice in comparision to transplanted rice **(Singh *et al.*, 2004).** The result was in agreement with **Karthika *et al.*, (2019)** in a weed management experiment under direct seeded rice and reported higher number of panicle than transplanted rice. In contrary to this **Akkas *et al.* (2006**) and **Bheru *et al*. (2016**) observed and reported taller plants under transplanted rice (106.1 cm) compared to direct-seeded rice (98.5 cm). Similarly, they stated that transplanted rice compared to direct seeded rice is able to produce more dry matter dry.

Nutrient Uptake and Nutrient use:

Puddled transplanted rice condition reduced leaching losses of nutrients resulted increased uptake and utilization by crop plants. **Chander and Pandey (1997)** and **Sandhya *et al.*, *(*2014)** in an experiment on rice under PTR and DSR noticed significantly higher N, P and K uptake than direct seeded rice. PTR minimized weed problem also helps in more availability of nutrients to crop.

Weed Dynamics:

Different rice ecosystems and cultural practices mostly determine dominant weed species, rice-weed competition and eventually, the weed control strategy **Saravanane *et al.*, (2021)**. The yield losses vary under rice establishment method. In general, more yield loss observed under direct seeded rice conditions in comparison to transplanted rice. **Dass *et al.*, (2017)** observed that, the yield losses may ascend to 50-60% in puddled transplanted rice and 70-80% in DSR**.**

Crop establishment methods also influenced the weed management practices and improved the weed control efficiency **(Parameshwari *et al.*, 2014). In** an experiment by them highest weed control efficiency of 90.4 and 88.1 per cent were recorded under transplanted and direct seeded rice, respectively. **Hassan *et al.*, (2010)** found that transplanted rice reduced the weed population as well as dry matter with higher weed control efficiency resulting in higher grain yield than WSR.

Crop establishment methods on yield attributes and yield

Puddled transplanted rice condition reduced losses of nutrients increased availability to crop plants as well as minimized crop weed competition resulted enhance crop yield and yield attributes **(Prasad *et al.*, 2010 and Iqbal *et al.*, 2017). From an experiment they reported enhanced yield contributing traits as well as grain yield.** Maximum 1000 grain weight was recorded in direct seeded rice followed by transplanted rice **Iqbal *et al.*, (2017)**.

Higher grain yields (4367 kg/ha) in transplanted rice which was significantly superior over direct seeded rice (2992 kg/ha) (**Prasad *et al.*, 2010)**. While, **Parameshwari *et al.* (2014)** observed no significant differences among different crop establishment methods in number of grains panicle^{-1}, panicle length and test weight.

Water saving:

Feeding to a vast population and meeting their water demands will become challenging in the future. Sustainability in agricultural water resource utilization is crucial for achieving global food security (Du *et al*. 2015). To address food scarcity caused by water scarcity, there are three approaches: (i) increasing water availability through wastewater recycling, (ii) enhancing water productivity through higher yields or better water use, or both, and (iii) addressing regional water scarcity through importing water in the form of food through virtual water trade (Fereres *et al*. 2011). The main objective of all three approaches is to maximize the use of available rainfall, make efficient use of limited irrigation water, and enhance crop water use efficiency through integrated techniques. This can be achieved through various practices and technologies, including (i) upgrading and optimizing irrigation and drainage systems, (ii) building and lining field channels and waterways, (iii) land leveling and shaping, (iv) constructing field drains, (v) conjunctive use of surface and groundwater together, (vi) implementing and regulating appropriate cropping patterns, (vii) introducing and enforcing rotational water distribution systems (viii) developing plans for providing inputs such as credit, seeds, fertilizers, and pesticides, and (ix) strengthening current extension, training, and demonstration programs in farmers' fields to conserve freshwater and increase irrigation efficiency.

Table. 1. Water use efficiency and water productivity of direct-seeded rice

S. No.	Season/Location	WUE or Water Productivity (WP) or % Water Saving	Reference
1	PAU, Ludhiana	In DSR, water productivity ranged from 0.40 to 0.46, compared to 0.29 to 0.39 kg grain m−3 irrigation water under transplanted rice. The water productivity under DSR is 17.9–27.5% higher compared to transplanted rice.	Gill *et al.* (2006)
2	Punjab, India	DSR with 20 kPa reduced irrigation input by 30–50% and increased water productivity without reducing productivity.	Yadav *et al.* (2011)
3	University of Agriculture, Faisalabad, Pakistan	DDSR has a water productivity of 1.4 kg grain m−3 and saved 8–12% of water compared to transplanted rice, which has a water productivity of 1.1 kg grain m−3 under sandy loam soil.	Ishfaq *et al.* (2020)

Research observations as reported by researcher's water productivity was more in DSR compared to TPR. The maximum water saving (39.4%) was recorded in DSR with sesbania co-culture. Water productivity of rice Pusa 44 was 0.45 kg m when grown in DSR without crop residue while it was 0.43 kg m with sesbania co-culture. The maximum water saving was 32.3% in DSR with sesbania. Bhandari *et al.,* (2020) reported that water consumption saving up to 60% as nursery raising, puddling, seepage and percolation are no longer needed as like in TPR. Similarly, Pathak *et al.,* (2011) reported that transplanted rice with continuous standing water has relatively high water inputs and low water productivity as compared to other technologies of rice cultivation water during the crop growth period and increased water productivity by 25-48%. Rice can be established by DSR once 150 mm rain or irrigation water has accumulated compared to 450 mm needed for transplanting.

Labour and cost saving:

In recent years, there have been concerns related to shortages of labor, which cause transplanting costs to rise and delay the planting. Direct seeding avoids to grow the seedling and transplanting, thus reducing the labour requirement for transplanting and nursery growing. Labor requirement for nursery raising, uprooting and transplanting of seedlings are saved to the extent of nearly 40% and the work cost is low. Human labour use also reduced to 40-45% and tractor use to 50-60% in DSR compared to transplanted rice **(Pathak *et al.*, 2011).** Zero-tilled-direct-seeded rice systems needed 34–60% less effort for mechanization than puddle-transplanted rice systems. Switching from PTR to wet-DSR saved 13–49% of labor (**Bhushan *et al*., 2007**). Direct-seeded rice uses family labor and relies less on paid personnel because the demand for labor is spread out over a longer period than with transplanted rice. On the other hand, according to researchers like **Bhatt *et al.* (2023)** direct-seeded rice requires 12–200% more labor to suppress weeds than puddle- transplanted rice but reduces labor and energy footprints.

Economics: -

The rising cost of rice cultivation, and decreasing profits with conventional practice (CT-PTR) farmers are showing interest in DSR. Growers likely prefer a technology that gives higher profit despite similar or slightly lower yield. The largest reductions in cost occurred in practices in which reduced or ZT was combined with dry-DSR. The observed cost reductions were largely due to either reduced labor cost or tillage cost or both under DSR systems. Direct seeding using drum seeder produced significantly higher net income Rs 34,953 per ha and returns per rupee investment (Rs 3.12) compared to net income Rs 30420 per ha and returns per rupee investment (Rs 2.66) recorded in transplanted system **(Kaur and Singh (2017), Younas *et al.* (2015), Awan *et al.* (2007) and Ali *et al.* (2012).**

Need for direct seeded rice:

Direct seeded rice (DSR) cultivation is imperative for agricultural sustainability **(Pathak *et al.*, 2011 and Bhandaria *et al*., 2020)** in various ways**:**

a) Direct seeding rice, was a common practice before green revolution in India, is becoming popular once again because of its potential to save water and labour.
b) It is gaining popularity as a feasible and best alternative method which overcome all the limitation of transplanting method.
c) It avoids basic operations in rice cultivation like puddling, transplanting and maintenance of standing water in rice field.
d) Absence of transplanting shock in DSR pull its maturity 7 to 10 days earlier than transplanted rice.
e) Labour required for nursery raising, uprooting and transplanting of seedlings are saved to the extent of about 40%.

f) Saving of water (up to 60%) as nursery raising, puddling, seepage and percolation are eliminated **(Pathak *et al.*, 2011).**

g) Rice is commonly grown by transplanting seedling into puddled soil Puddling benefits rice by reducing water percolation losses controlling weeds, facilitating easy seedling establishment and creating anaerobic condition to enhance nutrient availability.

h) But, repeated puddling adversely affects soil physical properties by destroying soil aggregates, reducing permeability in surface layers and forming hard pans at shallow depths, all which can negatively affect the following non-rice upland crop in rotation.

i) Moreover, puddling and transplanting require large amount of water and labour, both of which can become increasingly scare and expensive, making rice production less profitable. All these factors demand a major shift from puddled –transplanted rice production to direct seeding rice.

Constraints associated with DSR

Kaur and Singh (2017) and **Farooq *et al.* (2011)** elaborate the constraints experienced during direct seeded rice cultivation.

a) The emerging weeds are more competitive as compared to the simultaneously emerging DSR seedlings **Kaur and Singh (2017)**.

b) Lack of water layer in Wet- and Dry-DSR make these crops more prone to initial weed infestation which lacks otherwise in case of transplanting **Kaur and Singh (2017).**

c) Emergence of weedy rice**-** Weedy rice/red rice (O. Sativa, F. spontanea), has emerged as a serious concern to rice production in areas where direct seeding especially Dry-DSR widely replaces CT-PTR. Milling quality is also impaired if weedy rice gets mixed with rice seeds during harvesting. Weedy rice is difficult to control because of its genetic, morphological, and phenological similarities with rice. Selective control of weedy rice was never achieved at a satisfactory level with herbicides. To control weedy rice proper land preparation along with the stale seedbed technique using nonselective herbicides before planting rice has been recommended to reduce the density of weedy rice **Kaur and Singh (2017).**

d) Increases Soil born Pathogen Such as Nematodes**:** Root-knot nematodes pose a severe constraint when shift from PTR to DSR takes place. The root-knot nematode, also known as RKN, is the most devastating soil-borne disease for aerobic rice, and it is responsible for reduced yields. Root-knot nematode, *Meloidogyne graminicola* was first reported in 1963 from the Louisiana State University, Baton Rouge, USA **Kaur and Singh (2017).**

e) Higher emissions of nitrous oxide: Although direct seeding can help in reducing CH4 emissions, but aerobic soil conditions can also increase N2 O emissions **Kaur and Singh (2017).**

f) Nutrient disorders, especially N and micronutrients**:** Deficiencies of micronutrients are of major concern in DSR. A shift from PTR to DSR affect Zn availability to rice and it reduces because of reduced release of Zn from highly insoluble fractions in aerobic rice fields. Availability of Fe is often particularly high in anaerobic soils because of low redox potential **Kaur and Singh (2017).**

g) Stagnant yield: Yield decline in DSR has been reported, which may be due to various reasons viz., soil sickness, plant auto toxicity, presence of G. graminis var. graminis in dry-seeded rice fields and continuously growing DSR for more than two years **Farooq (*et al.*, 2011).**

h) Lodging: DSR is more prone to lodging as compared to PTR. Lodging makes the harvesting of the crop difficult and also reduces yield and impairs the quality of rice both in terms of appearance and taste. Rice cultivars having lodging resistant characteristics viz., intermediate plant heights, large stem diameters, thick stem walls and high lignin content should be preferred **Kaur and Singh (2017).**

i) Diseases and insect pests: DSR is susceptible to various diseases and rice blast is one of the most common and damage due to rice blast increases under water stress conditions, since the water level affects several processes such as liberation and germination of spores and infection in rice causing blast. The crop microclimate especially dew deposition is affected by water management which makes the environment congenial for host susceptibility. In DSR, the other disease and insect problems reported are sheath blight and dirty panicle, brown spot disease and plant hoppers as well as soil borne pathogenic fungus *viz*. *Gaeumannomyces graminis* var. graminis in dry-seeded rice in Brazil without additional irrigation **Kaur and Singh (2017)** and **Farooq (*et al.*, 2011).**

Innovations for promotion of DSR:

Now a day, sincere efforts have been made in promoting the DSR technology by various International, National and Private organizations. Breeders, agronomists and agricultural engineers have also concentrated their efforts in developing suitable cultivars, agronomic packages and need based implements for promoting the DSR. Some of the recent technological developments in the DSR are discussed below (**Pathak *et al*., 2011)**

i. **Innovations for promotion of DSR**: In recent years, sincere efforts have been made in promoting the DSR technology by various International, National and Private organizations. Breeders, agronomists and agricultural engineers have also concentrated their efforts in developing suitable cultivars, agronomic packages and need based implements for promoting the DSR. Some of the recent technological developments in the DSR are discussed below-

ii. **Zero tillage/reduced tillage:** Zero tillage has been established as cost saving, yield boosting and eco- friendly resource conservation technology in entire IGP. The multi-crop new generation zero till seed cum test planters with disk type coulters allow seeding in presence of anchored and loose residue.

iii. **Laser land leveler:** Traditionally, levelled fields, although look even but may have up to ± 6 cm or more deviations from the average elevation of the fields. With laser leveling, the field surface is smoothened to within ± 2 cm. Results of farmers participatory trials have indicated that laser assisted precision land leveling saved a minimum of 15 cm water in rice-wheat system and improved yield up to 25%. Precision leveling reduced or eliminated weed problem in the initial years and increased cultivable area by 3-6% due to elimination of many field bunds and irrigation channels.

iv. **Leaf colour chart (LCC) for N application:** Results indicated that agronomic efficiency of N in rice could be enhanced by real time N management using LCC (LCC = 3 for basmati rice and LCC = 4 for hybrid and high yielding medium fine to coarse grain rice). Its use saved N up to 17% in transplanted rice without any yield penalty.

v. **Weed management:** Weeds are major constraints responsible for low productivity in direct seeded rice crop. DSR have indicated that pre - emergence application of pendimethalin at 1 kg ha-1 dissolved in 500- 600 L of water followed by post emergence application of ready mix of chlorimuron + metsulfuron @ 4 g ha- 1 for broad leaved and sedges weed control or ethoxysulfuron @ 15 g ha- 1 for sedges and broad leaved weeds, or 2,4–D at 500 g ha-1 applied around 20 days after sowing for broad leaved weeds and Fenoxaprop @ 50 g ha-1 for grassy weeds have been found effective in realizing higher rice grain yield. Azimsulfuron is also performing well in controlling complex weed flora in DSR in Indo-Gangetic Plains.

Future perspective:

The system has been proved cost effective and farmers' friendly but require further improvement in technological approach to realize greater benefits. Following points are suggested for the consideration to the scientists, extension officers and policy makers **(Pathak *et al.*, 2011 and Bhandaria *et al.*, 2020)**

i. More research is needed to develop high yielding rice varieties suitable for DSR under different agro climatic conditions. Varieties must possess the desirable traits, viz. vigorous growth, weed suppressing ability, germinating ability under moisture stress, tolerant to micronutrient deficiency.

ii. There is need to improve the productivity of DSR which is low due to inadequate nutrient inputs, inefficient water management and problem associated with weed management.

iii. Timely DSR crop establishment during mid-May to mid-June (or 15-20 days before commencement of monsoon) is deciding factor for the success of the crop. Irrigation water supply must be ensured at the sowing time.

iv. A cooperative society with a cluster of villages for ensuring the availability of agri-inputs, laser land leveler, zero till machine, LCC, cono weeder at reasonable costs needs to be strengthened

v. Weeds are location specific and the nature and intensity of weed flora are usually governed by the ecosystems under which it is grown. There is need to give fine tuning to the low cost integrated weed management technology involving stale seed bed technique, suitable aerobic genotypes, cultural, physical, mechanical and use of low doses of herbicides for different ecosystems in the different regions.

vi. The problem of weedy rice is coming up in direct seeding rice especially in canal irrigated areas. Strategic approach in tackling this menace is very much required.

vii. Since the herbicidal application is highly technical, training to the rice growers is needed in respect of calibration of sprayers, preparation of herbicidal spray, importance of flat fan/flood Jet nozzles, method of herbicidal application and precautions in the herbicidal spray.

Conclusion:

DSR with appropriate agronomic interventions can produce similar yields as that of TPR and remains a feasible substitute for TPR under a labor and water shortage. Uncontrolled weeds in the field are reported to reduce yield up to 75% in DSR. An efficient weed-monitoring program is required, wherein different weed-management approaches namely cultural weed management through stale seedbed and crop residue mulch, utilizing crop-competitiveness by growing suitable cultivars and altering seed rate, row spacing, nutrient and water management can enhance the crop competitive ability. Enhanced NUE, efficient weed control, and a deeper comprehension of disease-pest interactions will all help to maximize DSR yields. Since rice production is being threatened by climate change, increased labor costs, water scarcity, and other issues, questions about alternatives are undoubtedly emerging. It is a workable substitute for TPR that has the potential to reduce labor costs, water, energy use, and the effects of climate change. About 34% less labor and 50% less water are used. Therefore, when the future of rice production is under risk due to the current global water shortage and rising labor costs, DSR is the most practical solution for achieving sustainable yields without overusing the natural resources that are already accessible.

References

Ali, M.A., Ladha, J.K., Rickman, J. and Laies, J.S., 2006. Comparison of different methods of rice establishment and nitrogen management strategies for lowland rice. *Journal of Crop Improvement*, *16*(1-2), pp.173-189.

Ali RI, Iqbal N, Saleem MU and Akhtar M, 2012. Effect of different planting methods on economic yield and grain quality of rice. *Int. J. Agric. Appl. Sci*. 4(1):28-34.

Awan TH, Ali I, Safdar ME, Ashraf MM and Yaqub M, 2007. Economic Effect of different plant establishment techniques on Rice, Oryza Sativa production. *J. Agric. Res*., 45(1):73-80

Bhandaria, S., Khanala, S. and Dhakalb, S., 2020. Adoption of Direct Seeded Rice (DSR) over puddled-Transplanted Rice (TPR) for resource conservation and increasing wheat yield. *Rev Food Agric.(RFNA), 1*(2), pp.44-51.

Bhatt, R., Oliveira, M.W., Verma, K.K., Garg, A.K., Kaur, G., Laing, A.M., Chandra, M.S. and Majumder, D., 2023. Challenges, Scope, and upcoming strategies for Direct Seeding of Rice: A Global Meta-analysis. *Agricultural Mechanization in Asia, Africa and Latin America*, 54(04), pp.12825-12863.

Bhushan, L., Ladha, J.K., Gupta, R.K., Singh, S., Tirol-Padre, A., Saharawat, Y.S., Gathala, M. and Pathak, H., 2007. Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. Agronomy Journal, 99(5), pp.1288-1296.

Bista, B., 2018. Direct seeded rice: A new technology for enhanced resource-use efficiency. *International Journal of Applied Sciences and Biotechnology*, 6(3), pp.181-198.

Dass, A., Shekhawat, K., Choudhary, A.K., Sepat, S., Rathore, S.S., Mahajan, G. and Chauhan, B.S., 2017. Weed management in rice using crop competition-a review. *Crop protection*, 95, pp.45-52.

Du, T.; Kang, S.; Zhang, J.; Davies, W.J., 2015. Deficit irrigation and sustainable water-resource strategies in agriculture for China's food security. J. Exp. Bot. 66, 2253–2269.

Farooq, M.K.H.M., Siddique, K.H., Rehman, H., Aziz, T., Lee, D.J. and Wahid, A., 2011. Rice direct Pathak, seeding: Experiences, challenges and opportunities. *Soil and tillage research*, *111*(2), pp.87-98.

Fereres, E.; Orgaz, F.; Gonzalez-Dugo, V., 2011. Reflections on food security under water scarcity. J. Exp. Bot., 62, 4079–4086.

Gill, M.S.; Kumar, A.; Kumar, P., 2006. Growth and yield of rice (Oryza sativa L.) cultivars under various methods and ties of sowing. Indian J. Agron., 51, 123–127.

Hassan G, Tanveer S, Khan NU, Munir M., 2010. Integrating cultivars with reduced herbicide rates for weed management in maize. *Pakistan Journal of Botany*; 42(3):1923-1929.

Iqbal MZ, Hussain M, Rasheed A., 2017 Direct seeded rice: purely a site specific technology. *International Journal of Advanced Research in Biological Sciences*. 4(1):53-57.33.

Ishfaq, M., Akbar, N., Anjum, S.A. and Anwar-Ijl-Haq, M., 2020. Growth, yield and water productivity of dry direct seeded rice and transplanted aromatic rice under different irrigation management regimes. *Journal of Integrative Agriculture*, *19*(11), pp.2656-2673.

Joshi, E., Kumar, D., Lal, B., Nepalia, V., Gautam, P. and Vyas, A.K., 2013. Management of direct seededrice for enhanced resource-use efficiency. *Plant Knowledge Journal*, *2*(3), pp.119-134.

Karthika R, Subramanian E, Ragavan T, Kumutha K., 2019 Studies on crop weed competition and weed management in direct seeded rice under puddled and unpuddled conditions. International Journal of Chemical Studies. 7(3):2769-2773.

Kaur, J. and Singh, A., 2017. Direct seeded rice: Prospects, problems/constraints and researchable issues in India. *Current Agriculture Research Journal*, 5(1), p.13.

Kumhar, B.L., Chavan, V.G., Rajemahadik, V.A., Kanade, V.M., Dhopavkar, R.V., Ameta, H.K. and Tilekar, R.N., 2016. Effect of different rice establishment methods on growth, yield and different varieties during kharif season. Int. J. Plant Ani Environ. Sci, 6, pp.127-132.

Mahapatra, B.S., Bhupenchandra, I., Devi, S.H., Kumar, A., Chongtham, S.K., Singh, R., Babu, S., Bora, S.S., Devi, E.L. and Verma, G., 2021. Aerobic Rice and its significant perspective for sustainable crop production. *Indian Journal of Agronomy*, *66*(4), pp.383-392.

Nawaz, A., Rehman, A.U., Rehman, A., Ahmad, S., Siddique, K.H. and Farooq, M., 2022. Increasing sustainability for rice production systems. *Journal of Cereal Science*, 103, p.103400.

Parameswari, Y.S., Srinivas, A., Prakash, T.R. and Narendar, G., 2014. Effect of different crop establishment methods on rice (Oryza sativa L.) growth and yield–A review. Agricultural Reviews, 35(1), pp.74-77.

Pathak, H., Tewari, A.N., Sankhyan, S., Dubey, D.S., Mina, U., Singh, V.K. and Jain, N., 2011. Direct-seeded rice: potential, performance and problems-A review. *Current Advances in Agricultural Sciences* (An International Journal), 3(2):77-88.

Prasad TVR, Sanjay MT, Denesh GR, Kumar HSR, Ananda N, Lokesh DS, 2010. Influence of time of sowing and weed control methods on yield and economics of direct seeded rice. In: Proceeding of the Biennial Conference of Indian Society of Weed Science on “Recent Advances in Weed Science Research-2010” February, 2010, 25-26.

Sandhya KM, 2014. Appraisal of nutrient requirement of rice (Oryza sativa L.) under different crop establishment techniques. M.Sc. (Agri.) Thesis, Acharya N. G. Ranga Agricultural University.

Saravanane, P., Pavithra, M. and Vijayakumar, S., 2021. Weed management in direct seeded rice. *Indian Farming*, 71(04), pp.61-64.

Singh RK, Namdeo KN 2004. Effect of fertility levels and herbicides on growth, yield and nutrient uptake of direct seeded rice (Oryza sativa). *Indian Journal of Agronomy*. 49(1):34-36.

Subhash Chander, S.C. and Jitendra Pandey, J.P., 1997. Nutrient removal by scented basmati rice (Oryza sativa) and associated weeds as affected by nitrogen and herbicides under different rice cultures.

Tripathi RS, Raju R, Thimmappa K., 2014. Economics of direct seeded and transplanted methods of rice production in Haryana. *Oryza*. 51(1):70-73.

Tyagi, R. and Chander, J.K.S., 2020. Comparative analysis between direct seeded rice and conventional transplanted rice method. *The Pharma Innovation Journal*, *9*(6), pp.236-238.

Yadav, S.; Humphreys, E.; Kukal, S.S.; Gill, G.; Rangarajan, 2011 R. Effect of water management on dry seeded and puddled transplanted rice, Part 2, Water balance and water productivity. Field Crops Res. 120, 123–

132.

Younas, M., Rehman, M.A., Hussain, A., Ali, L. and Waqar, M.Q., 2015. Economic comparison of direct seeded and transplanted rice: Evidences from adaptive research area of Punjab Pakistan. *Asian J Agri. Biol*, 4(1):1-7.