Original Research Article

Effect of crop establishment, intermittent submergence and precision nitrogen management on growth and yield of rice

Abstract

The traditional production practices of rice not only wastes water, but it is also expensive, requiring a substantial manpower input, is energy-intensive, and is a difficult and time-consuming procedure, making rice cultivation less profitable. Effective water and nitrogen management practices are essential requirement for better rice growth and yield. Keeping these facts in view the present investigation was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during *kharif* and *rabi* season of 2019-20 and 2020-21, in South-eastern part of Varanasi city of India (25°18′N latitude and 83°31′E longitude at an altitude of 128.93 meter above sea level). The experimental soil was Gangetic alluvial sandy clay loam. The experiment was laid out in a split-plot design during both years with three replications. Crop establishment (as factor A) and Irrigation scheduling (as factor B) were allocated to the main plot, and nitrogen management in subplots. In main plot, two crop establishment methods (Factor A) *i.e.* CE_1: Puddle Transplanted Rice (PTR) & CE_2: Direct Seeded Rice (DSR) and three irrigation regime (Factor B) *i.e.* I_1: Continuously submerged (CS) of 5 ± 2 cm depth, I_2: Intermittent submergence (IS) of 5 ± 2 cm and irrigation after five days of disappearance of water from the soil surface & I_3: Intermittent submergence of 5 ± 2 cm and irrigation after ten days of water disappearance from the soil surface were taken. In sub plot treatment four nitrogen management practices *i.e.* N_1: recommended dose of nitrogen (RDN), N_2: LCC threshold ≤ 4, N_3: SPAD 30 & N_4: Rice-Wheat Crop Manager recommendation. Results showed that Direct Seeded Rice (DSR) and Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water among the main plot and nitrogen recommendation based on Rice-Wheat Crop Manager (RWCM) recorded higher plant height, number of tillers, chlorophyll content and grain yield of rice over rest of the treatment. DSR recorded a higher grain yield by 9.5 % over Conventional method, whereas I_2 recorded 7.5 % more grain yield over $I_1$and RWCM (N_4) recorded 17% more grain yield over Recommended Nitrogen Dose (RDN). It can be concluded that DSR with intermittent submergence and precision nitrogen management can improve the growth and yield of rice under climatic condition of Eastern Uttar Pradesh.

1. Introduction:

Rice is the world's second-largest crop by area and production after wheat**.** In India, rice occupies 45 million hectares with a production of 127.9 million tonnes and an average yield of 2.84 t ha^{-1} (Ministry of Agriculture, Directorate of Economics and Statistics 2020). In India, it accounts for more than 55 per cent of cereal production, providing direct employment to 70% of the people in rural areas. As it is the staple food for more than 65% of the population, our national food security hinges on the growth and stability of its production.

There are several ways for rice cultivation worldwide: wet seeding, which involves sowing pre-germinated seeds in wet puddled soils; and transplanting, which involves replanting rice seedlings grown in a nursery to puddled soils (Chen *et al.,* 2017). Generally, in India, rice is grown as a transplanted crop; it is traditionally grown by transplanting into puddled soil (land preparation with wet tillage) in June/July. (Mahajan *et al.,* 2012). This production system not only leads to wastage of water but is also costly, requires a significant labour input (300–350 man-h ha^{-1}), is energy-intensive (2016–

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2390 MJ ha^{-1}), and is a cumbersome and time-consuming process, which makes rice production less profitable. (Bhatt *et al.,* 2016). Increasing labour, diesel, and electricity costs are also considered severe issues (Chauhan *et al.,* 2012). All these factors have threatened the productivity and sustainability of rice-based systems and demand a significant shift from the current transplanted rice production system. Aerobic or partially-aerobic rice cultivation techniques like direct-seeding of rice (DSR) are gaining recognition for resource conservation (water in particular) and environmental gains (Mishra *et al.,* 2017). There are three principal methods of direct seeding of rice (DSR): dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre-germinated seeds on wet puddled soils), and water seeding (seeds are sown into standing water). Direct seeding offers such advantages compared to traditional transplanting as faster planting, reduced labour by up to 60%, less drudgery, earlier crop maturity by 7 to 10 days with less water requirement (12–36%), less methane emission, often higher profitability, and the rising interest in conservation agriculture (Mahajan *et al.,* 2013; Chauhan *et al.,* 2012).

Recent projections suggest that there will be a severe water shortage in the following decades. It is suggested that rice farmers use water more effectively because of the rise in irrigation water costs and a decrease in return. These necessitate the adoption of water-efficient techniques for rice production to reduce water use in the agricultural sector while maintaining or increasing yield to support a growing population (Saha *et al.,* 2015; Brar *et al.,* 2018).Alternate wetting and drying (AWD) are among the most widely promoted water-saving irrigation technique introduced by the International Rice Research Institute (IRRI) to cope with the increasing threat of water scarcity in rice cultivation (Yang *et al.,* 2017). Under this system, fields are subjected to intermittent flooding (alternate cycles of saturated and unsaturated conditions) where the water of about 2–5 cm is applied at an interval of 1 to 10 days, depending on the soil type and weather conditions, followed by the disappearance of pond water from the soil surface and appearance of visible signs of some fine cracks on the soil surface and then re-flooded up to 5 cm above the surface. (Lampayan*et al.,* 2015). This cycle is repeated until before the rice harvest, except for the flowering stage.

As fertilizer N has been generally managed following blanket recommendations consisting of two or three split applications of present rates of the total amount of N, improvement in N use efficiency could only be achieved by a limit. Various factors such as spatial soil N variability, agro-climatic circumstances, time and rate of N fertilizer application, and varietal differences significantly hamper the efficient use of fertilizer N when broad-based general or blanket recommendations are followed. Therefore, effective N management during crop growth is critical to efficient crop production and enhancing crop yield and quality. (Peng *et al.,* 2010; Zhao *et al.,* 2017). Adjusting N input to an economically and ecologically compatible level would require quantitative information on the N status of rice plants. An ideal indicator of crop N status should be able to detect deficiencies and excesses of N supply and provide a fast diagnosis to allow dressing correction for efficient fertilizer management during crop growth. (Yao *et al.*,2014).

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2. Materials and Method:

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The present investigation was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi during *kharif* and *rabi* season of 2019-20 and 2020-21, in South-eastern part of Varanasi city of India (25°18′N latitude and 83°31′E longitude at an altitude of 128.93 meter above sea level). The experimental soil was Gangetic alluvial sandy clay loam. The experiment was laid out in a split-plot design during both years with three replications. Crop establishment (as factor A) and Irrigation scheduling (as factor B) were allocated to the main plot, and nitrogen management to subplots. In main plot, two crop establishment methods (Factor A)*i.e.*CE_1: Puddle Transplanted Rice (PTR)& CE_2: Direct Seeded Rice (DSR) and three irrigation scheduling (Factor B) *i.e.* I_1:Continuously submerged (CS) of 5 ± 2 cm depth, I_2: Intermittent submergence (IS) of 5 ± 2 cm and irrigation after five days of disappearance of water from the soil surface & I_3: Intermittent submergence of 5 ± 2 cm and irrigation after ten days of water disappearance from the soil surface were taken. In sub plot treatment four nitrogen management practices *i.e.* N_1: recommended dose of nitrogen (RDN), N_2: LCC threshold ≤ 4, N_3: SPAD 30 & N_4: Rice – Wheat Crop Manager recommendation. A buffer of 1.0 m width surrounded each main plot, whereas the subplot was surrounded by 1.0 m width to protect the plots from accidental irrigation and water gain through seepage. The application of nutrients to the test crop was made based on recommendations for uniformly using phosphorous, potassium, and zinc (60-60-5 kg ha^{-1}) for all the treatments. The sources used for nitrogen, phosphorous, potassium, and zinc were urea (46% N), single super phosphate (16% P_2O_5, 12% S, and 21% Ca), muriate of potash (60% K2O), and zinc sulphate monohydrate (33%), respectively. The total diammonium phosphate and potash dose was applied when sowing/transplanting as basal. Zinc was applied through two foliar sprays. Other agronomic practices were carried out as per the state recommendations.Nitrogen was applied as per treatments through leaf colour chart (LCC) threshold ≤ 4, SPAD 30, and Rice-Wheat crop manager recommendation, whereas in the recommended dose of nitrogen (120 kg ha-1), one-fourth dose was applied as basal, the half dose was applied at the maximum tillering stage, and the remaining one-fourth dose at the panicle initiation stage.

3. Result:

3.1 Growth parameters

3.1.1 Plant height

Direct-seeded rice recorded significant maximum plant height in comparison to puddled transplanted rice at 60, 90 and at harvest stages, whereas, at 30 DAS, both crop establishment practices failed to reach up to the level of significance during both the year of study. Marked variations in plant height were recorded due to different water management practices at all the growth stages during both years. At 30 DAS/DAT, among the different water management practices, I_2 (Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface) recorded significantly higher plant height (38.85 and 39.90 cm) over I_1 (continuously submerged at 5 cm depth) and I_3 (Intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface). A similar trend was observed at 60, 90 DAS/DAT and at the harvest stage during both the years of study.
Nitrogen management significantly affected plant height at all the growth stages except at 30 DAS/DAT. Use of the Rice-Wheat crop manager's recommendation, being statistically at par with SPAD 30-based Nitrogen management and LCC threshold ≤ 4, brought significantly higher plant height over the required dose of nitrogen during both years in all growth stages. Whereas, at 60 DAS/DAT LCC based nitrogen management was found at par with the required dose of nitrogen. The minimum plant height was observed with the treatment in which the recommended dose of nitrogen was applied for both years of investigation at all the growth stages.

Table 1: Effect of crop establishment, irrigation schedule, and precision nitrogen managementon plant height (cm) of rice at various crop growth stages

Treatments	30 DAS/DAT		60 DAS/DAT		90 DAS/DAT		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
Main-plots treatment								
Crop establishment								
CE_1: Puddle Transplanted Rice (PTR)	34.47	35.37	75.42	77.06	100.22	102.42	102.22	104.83
CE_2: Direct Seeded Rice (DSR)	37.53	38.47	79.22	80.99	105.30	107.44	107.31	109.93
SEm±	0.57	0.56	1.17	1.20	1.54	1.58	1.57	1.61
LSD (*P*=0.05)	1.80	1.77	3.69	3.77	4.85	4.97	4.95	5.07
Irrigation scheduling								
I_1:Continuously submerged at 5 cm depth	35.51	36.33	77.69	79.38	103.20	105.84	105.70	108.41

I_2: Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface	39.0	39.90	81.65	83.58	106.41	109.24	108.91	111.49
I_3: Intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface	33.48	34.53	72.61	74.12	98.68	99.71	99.68	102.24
SEm±	0.70	0.69	1.43	1.47	1.89	1.93	1.92	1.97
LSD (*P*=0.05)	2.21	2.17	4.52	4.62	5.94	6.09	6.06	6.21
Sub-plots treatment								
Nitrogen Management								
N_1: RDN	34.50	35.18	72.61	74.33	96.65	97.98	98.64	100.91
N_2: LCC threshold ≤ 4	35.00	35.98	76.30	78.19	101.05	103.71	102.97	105.16
N_3: SPAD 30	36.50	37.33	78.86	80.35	104.95	107.53	107.09	109.55
N_4: Rice-Wheat Crop Manager Recommendation	38.00	39.18	81.52	83.23	108.42	110.49	110.35	113.89
SEm±	0.63	0.62	1.30	1.33	1.73	1.77	1.77	1.81
LSD (*P*=0.05)	1.81	1.78	3.73	3.81	4.98	5.07	5.07	5.20

3.1.2Number of tillers

Among the crop establishment methods, direct-seeded rice recorded a maximum no. of tillers (36.18 and 38.85) compared to PTR (28.89 and 30.76) at 30 DAS/DAT during both years, respectively. With respect to no. of tillers, similar trends were observed at 60, 90 DAS/DAT and the harvest stage during the research period. Water management practices also influenced the number of tillers at all growth stages in both experimental years. At 30 DAS/DAT, the water management practice I_2 (intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface) resulted in a significantly higher number of tillers (34.97 and 37.24) compared to I_1 (continuously submerged at 5 cm depth) and I_3 (intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface) in both years. At 60, 90 DAS/DAT, and at the harvest, similar trends were observed in both study years.Further, among the different nitrogen management options, the highest number of tillers was recorded using the Rice-Wheat crop manager. Still, it was comparable to SPAD 30-based nitrogen management and LCC threshold ≤ 4, all bringing significant improvement over RDN. Whereas during the first year of experimentation, the number of tillers was statistically similar to the required dose of nitrogen at 60 DAS/DAT. Moreover, RDN had a minimum no. of tillers at all the growth stages during each year of study.

Table 2: Effect of crop establishment, irrigation schedule, and precision nitrogen management on tiller count (per running meter) of rice at various crop growth stages

Treatments	30 DAS/DAT		60 DAS/DAT		90 DAS/DAT		At harvest	
	2019	2020	2019	2020	2019	2020	2019	2020
Main-plots treatment								
Crop establishment								
CE_1: Puddle Transplanted Rice (PTR)	28.89	30.76	64.38	67.29	61.25	64.87	57.45	61.54
CE_2: Direct Seeded Rice (DSR)	36.18	38.85	68.10	72.48	65.51	70.13	62.14	66.62
SEm±	0.51	0.55	1.07	0.99	0.90	0.95	0.98	1.04
LSD (*P*=0.05)	1.62	1.74	3.39	3.12	2.83	3.00	3.08	3.28
Irrigation scheduling								
I_1:Continuously submerged at 5 cm depth	32.41	34.68	66.00	69.64	63.62	67.44	60.83	65.11

I_2: Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface	34.97	37.24	70.92	74.76	67.30	71.72	64.31	68.30
I_3: Intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface	30.22	32.49	61.81	65.27	59.22	63.34	54.25	58.82
SEm±	0.63	0.67	1.32	1.21	1.10	1.17	1.20	1.27
LSD (*P*=0.05)	1.98	2.13	4.15	3.82	3.46	3.68	3.78	4.02
Sub-plots treatment								
Nitrogen Management								
N_1: RDN	30.38	32.26	61.36	64.80	58.30	62.42	54.39	59.36
N_2: LCC threshold ≤ 4	31.63	34.08	64.86	68.44	61.17	65.29	57.77	62.44
N_3: SPAD 30	33.34	35.99	68.52	72.26	65.91	70.03	61.61	65.65
N_4: Rice-Wheat Crop Manager Recommendation	34.77	36.88	70.23	74.04	68.14	72.26	65.41	68.86
SEm±	0.59	0.64	1.19	1.10	1.00	1.06	1.07	1.15
LSD (*P*=0.05)	1.70	1.82	3.41	3.15	3.27	3.05	3.08	3.30

3.1.3 Chlorophyll content (SPAD Value)

Chlorophyll content in the leaves (SPAD value) did not experience a significant change due to the effect of crop establishment and nitrogen management during both years. Irrigation scheduling significantly effected the chlorophyll content in leaves (SPAD value) in all stages of observation except for in 30 DAS/DAT. Irrigation scheduling at Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface (I_2) resulted in the highest chlorophyll content in leaves at 60, 90 DAS/DAT and harvest stage. The lowest chlorophyll content was recorded under Intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface (I_3).

Table 3: Effect of crop establishment, irrigation schedule, and precision nitrogen management on chlorophyll content in leaves (SPAD value) of rice at various crop growth stages

Treatments	30 DAS/DAT		60 DAS/DAT		90 DAS/DAT		Grain yield (qt. ha^{-1})	
	2019	2020	2019	2020	2019	2020	2019	2020
Main-plots treatment								
Crop establishment								
CE_1: Puddle Transplanted Rice (PTR)	30.99	31.86	35.40	36.00	30.79	31.00	42.54	43.83
CE_2: Direct Seeded Rice (DSR)	31.51	32.39	36.09	36.24	31.34	31.59	46.61	48.22
SEm +	0.43	0.45	0.36	0.36	0.31	0.31	0.74	0.76
LSD (*P*=0.05)	NS	NS	NS	NS	NS	NS	2.22	2.30
Irrigation scheduling								
I_1:Continuously submerged at 5 cm depth	31.21	32.08	35.74	36.11	31.08	31.26	45.01	46.46
I_2: Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface	31.97	32.86	36.84	37.23	31.99	32.22	48.70	50.15
I_3: Intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface	30.57	31.42	34.65	35.01	30.14	30.40	40.02	41.47
SEm±	0.53	0.55	0.44	0.44	0.38	0.38	0.74	0.76
LSD (*P*=0.05)	NS	NS	1.37	1.39	1.19	1.20	2.22	2.30
Sub-plots treatment								

Nitrogen Management								
N_1: RDN	31.07	31.94	35.41	35.77	30.61	30.87	40.86	41.76
N_2: LCC threshold ≤ 4	31.18	32.05	35.60	35.98	30.98	31.27	43.11	44.95
N_3: SPAD 30	31.33	32.21	35.85	36.21	31.21	31.43	46.32	47.53
N_4: Rice-Wheat Crop Manager Recommendation	31.41	32.29	36.11	36.51	31.47	31.61	48.02	49.87
SEm±	0.49	0.51	0.40	0.41	0.35	0.35	0.70	0.69
LSD (P=0.05)	NS	NS	NS	NS	NS	NS	2.19	2.27

3.2 Grain yield

Direct-seeded rice displayed superiority over puddled transplanted rice in terms of grain yield during both the years of study. DSR recorded a grain yield of 46.61 and 48.22 quintal ha^{-1} in the first and second year, respectively, while PTR with a lower grain of 42.54 and 43.83 quintal ha^{-1}, respectively.The effect of Irrigation scheduling was found significant on the grain yield of rice during both years. Water management with intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water from the soil surface (I_2) resulted in significantly higher grain yield over all other treatments at test. The highest grain yield (48.70 and 50.15 qt. ha^{-1} in the first and second year, respectively) was recorded under I_2, followed by I_1 (45.01 and 46.46 qt. ha^{-1}, respectively). The lowest seed yield (40.02 and 41.47 qt. ha^{-1}, respectively) was observed under intermittent submergence of 5 ± 2 cm and irrigation after 10 days of disappearance of water from the soil surface (I_3). A significant influenced of nitrogen management was observed on the grain yield of rice during the experimentation period. Management of nitrogen through Rice-Wheat Crop Manager Recommendation (N_4) resulted in significantly higher grain yield over the rest of the management treatments.The highest grain yield of 48.02 and 49.87 qt. ha^{-1} in the first and second year, respectively was recorded under N_4, which was 3.57, 10.22 and 14.91% higher over N_3, N_2 and N_1, respectively.

4. Discussion:

The final yield of a crop depends largely on the success of growth and development in individual plants, which is influenced by crop management practices such as establishment methods, irrigation and fertilization. Maintaining optimal soil-plant-atmosphere conditions through a combination of agronomic manipulations leads to the sustainable exploitation of crop yield potential within the local environment, specifically leveraging edaphic factors and genotypes to the crop's advantage (Bailey-Serres *et al.,* 2019).

DSR outperformed TPR for crop stand, tiller density, and leaf area development. Higher seedling vigour in DDSR can lead to early canopy cover, increased light interception, and higher WUE (Farooq *et al*., 2011; Anwar *et al*., 2011). In TPR, root damage caused by nursery uprooting and transplanting trauma can inhibit early growth and vigour. Yadav *et al.* (2011) found that DSR had greater growth than TPR, which is consistent with our findings. Alternate wetting and drying improved the number of productive tillers, while less water decreased the tillering density and number of productive tillers. Our results are consistent with findings of previous studies which show that AWD has an ability to increase productive tillers and reduces redundant growth by altering leaf angles, improving root health, shoot growth and LAI (Norton *et al*. 2017; Pascual and Wang 2017).Optimal nutrient use during SSNM may lead to increased cell division, enlargement, photosynthesis, and protein synthesis, resulting in quantitative increases in plant growth characteristics such as tillering (Singh *et al*., 2018). Shahi *et al*. (2022) found similar results.

The yield of paddy in direct seeding by rice-wheat seeder for all the varieties may be highest because of better root establishment, higher effective tillers and uniform plant geometry. These results are in close conformity with finding of Sharma *et al*. (2019) and Gill *et al*. 2014. Higher yields under AWD might be attributable to improved grain filling and greater root proliferation to absorb more water and nutrients (Pascual and Wang 2017). Furthermore, AWD raises effective tiller percentage and glucose translocation to grain, decreases spikelet sterility, and boosts grain weight (Yang and Zhang 2010). Post-anthesis AWD improves grain filling rate because to increased enzyme activity, which increases grain production (Zhang *et al*. 2012).Improved nutrient delivery throughout rice's active growth and development stages might explain the increase in yield-contributing traits under SSNM-based treatments (Singh *et al*. 2014). Shahi *et al*. (2022) reported similar results.

5. Conclusion:

Rice is the world's second-largest crop by area and production after wheat which is essential to the country's food security, accounting for about 42% of the total food grain production and about 20% of the national agricultural GDP. The traditional production practices of rice not only wastes water, but it is also expensive, requiring a substantial manpower input, is energy-intensive, and is a difficult and time-consuming procedure, making rice cultivation less profitable. Effective water and nitrogen management practices are essential requirement for better rice growth and yield. These problems play an important cause for shift towards direct seeded rice instead of present transplanted rice production system along with alternate wetting drying irrigation and site specific nutrient management practices. Results showed that Direct Seeded Rice (DSR) and Intermittent submergence of 5 ± 2 cm and irrigation after 5 days of disappearance of water among the main plot and nitrogen recommendation based on Rice-Wheat Crop Manager (RWCM) recorded higher plant height, number of tillers, chlorophyll content and grain yield of rice over rest of the treatment. It can be concluded that DSR with intermittent submergence and precision nitrogen management can improve the growth and yield of rice under climatic condition of Eastern Uttar Pradesh.

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References:

Chen S, Ge Q, Chu G, Xu C, Yan J, Zhang X, Wang D. Seasonal differences in the rice grain yield and nitrogen use efficiency response to seedling establishment methods in the Middle and Lower reaches of the Yangtze River in China. Field Crops Research. 2017 Apr 1;205:157-69.

Mahajan G, Chauhan BS, Timsina J, Singh PP, Singh K. Crop performance and water-and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. Field Crops Research. 2012 Aug 12;134:59-70.

Bhatt R, Kukal SS, Busari MA, Arora S, Yadav M. Sustainability issues on rice–wheat cropping system. International Soil and Water Conservation Research. 2016 Mar 1;4(1):64-74.

Chauhan BS, Mahajan G, Sardana V, Timsina J, Jat ML. Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. Advances in agronomy. 2012 Jan 1;117:315-69.

Mishra AK, Khanal AR, Pede VO. Is direct seeded rice a boon for economic performance? Empirical evidence from India. Food Policy. 2017 Dec 1;73:10-8.

Mahajan G, Chauhan BS, Gill MS. Dry-seeded rice culture in Punjab State of India: lessons learned from farmers. Field Crops Research. 2013 Mar 20;144:89-99.

Saha S, Singh YV, Gaind S, Kumar D. Water productivity and nutrient status of rice soil in response to cultivation techniques and nitrogen fertilization. Paddy and water environment. 2015 Oct;13:443-53.

Brar AS, Buttar GS, Sharma R. Water and energy productivity of rice as influenced by duration of cultivars, dates of transplanting and irrigation regime in north-western India. Paddy and water environment. 2018 Oct;16:655-63.

Yang J, Zhou Q, Zhang J. Moderate wetting and drying increases rice yield and reduces water use, grain arsenic level, and methane emission. The Crop Journal. 2017 Apr 1;5(2):151-8.

Lampayan RM, Rejesus RM, Singleton GR, Bouman BA. Adoption and economics of alternate wetting and drying water management for irrigated lowland rice. Field Crops Research. 2015 Jan 1;170:95-108.

Peng S, Buresh RJ, Huang J, Zhong X, Zou Y, Yang J, Wang G, Liu Y, Hu R, Tang Q, Cui K. Improving nitrogen fertilization in rice by sitespecific N management. A review. Agronomy for sustainable development. 2010 Sep;30:649-56.

Zhao B, Ata-Ul-Karim ST, Liu Z, Ning D, Xiao J, Liu Z, Qin A, Nan J, Duan A. Development of a critical nitrogen dilution curve based on leaf dry matter for summer maize. Field Crops Research. 2017 Jul 1;208:60-8.

Yao X, Ata-Ul-Karim ST, Zhu Y, Tian Y, Liu X, Cao W. Development of critical nitrogen dilution curve in rice based on leaf dry matter. European Journal of Agronomy. 2014 Apr 1;55:20-8.

Bailey-Serres J, Parker JE, Ainsworth EA, Oldroyd GE, Schroeder JI. Genetic strategies for improving crop yields. Nature. 2019 Nov 7;575(7781):109-18.

Farooq MK, Siddique KH, Rehman H, Aziz T, Lee DJ, Wahid A. Rice direct seeding: Experiences, challenges and opportunities. Soil and Tillage Research. 2011 Jan 1;111(2):87-98.

Anwar P, Juraimi AS, Puteh A, Selamat A, Man A, Hakim A. Seeding method and rate influence on weed suppression in aerobic rice. African Journal of Biotechnology. 2011;10(68):15259-71.

Humphreys E, Kukal SS, Gill G, Rangarajan R. Effect of water management on dry seeded and puddled transplanted rice: Part 2: Water balance and water productivity. Field Crops Research. 2011 Jan 14;120(1):123-32.

Sudhir-Yadav SY, Humphreys E, Kukal SS, Gill G, Rangarajan R. Effect of water management on dry seeded and puddled transplanted rice: Part 2: Water balance and water productivity. 2011.

Norton GJ, Shafaei M, Travis AJ, Deacon CM, Danku J, Pond D, Cochrane N, Lockhart K, Salt D, Zhang H, Dodd IC. Impact of alternate wetting and drying on rice physiology, grain production, and grain quality. Field Crops Research. 2017 Apr 1;205:1-3.

Pascual VJ, Wang YM. Utilizing rainfall and alternate wetting and drying irrigation for high water productivity in irrigated lowland paddy rice in southern Taiwan. Plant Production Science. 2017 Jan 2;20(1):24-35.

Singh H, Singh UP, Singh SP, Singh Y. Effect of crop establishment and nutrient management on productivity and profitability of rice under rice-wheat system. Int. J. Chem. Stud. 2018;6(3):165-70.

Shahi UP, Singh VK, Kumar A, Upadhyay PK, Rai PK. Site-specific nutrient management: Impact on productivity, nutrient uptake and economics of rice-wheat system. Indian J. Agric. Sci. 2022; 92:195-8.

Gill JS, Walia SS, Gill RS. Direct seeded rice: An alternative rice establishment technique in north-west India–A review. International Journal of Advanced Research. 2014;2(3):375-86.

Sharma S, Rout KK, Khanda CM, Tripathi R, Shahid M, Nayak A, Satpathy S, Banik NC, Iftikar W, Parida N, Kumar V. Field-specific nutrient management using Rice Crop Manager decision support tool in Odisha, India. Field Crops Research. 2019 Sep 1;241:107578.

Yang J, Zhang J. Crop management techniques to enhance harvest index in rice. Journal of experimental botany. 2010 Jul 1;61(12):3177-89.

Zhang H, Li H, Yuan L, Wang Z, Yang J, Zhang J. Post-anthesis alternate wetting and moderate soil drying enhances activities of key enzymes in sucrose-to-starch conversion in inferior spikelets of rice. Journal of Experimental Botany. 2012 Jan 1;63(1):215-27.

Singh VK, Dwivedi BS, Tiwari KN, Majumdar K, Rani M, Singh SK, Timsina J. Optimizing nutrient management strategies for rice–wheat system in the Indo-Gangetic Plains of India and adjacent region for higher productivity, nutrient use efficiency and profits. Field Crops Research. 2014;164:30-44.