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Comparative Study of Drip Irrigated Dry Direct Seeded Rice and Conventionally Flooded Transplanted Rice Productions

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Authors' contributions

This work was carried out in collaboration among all authors. Author KRK wrote original draft. Authors KRK and CAK performed the methodology. Authors KRK investigated the study. Authors KS and MLP conceptualized the research work. Authors KRK and KPCR did data curation. Authors KS supervised the study. Author KS and MLP did searched for resources. Authors KS and CAK did data validation. Authors KPCR and KPCR reviewed and edited the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted to compare the growth, yield and water use in drip-irrigated aerobic rice and conventionally flooded transplanted rice. The experimental design was split-plot design with 3 varieties in the main plot and 2 levels of irrigation (1.0 Epan& 1.5 Epan) in combination with 2 doses of N (100 & 125% of recommended dose of fertilizers) in the sub-plot and replicated thrice. An observation trial with these 3 varieties under transplanted conditions with 100 & 125% N was taken up. The experiment was conducted during Kharif, 2022 & 2023 at College Farm, College of Agriculture, Rajendranangar, Hyderabad, Telangana, India. In each variety, the best-performing irrigation level was found at 100% N & 125% N. Best-performing treatments under dry direct-seeded (DDSR) conditions was compared with conventionally flooded transplanted rice (CFTPR) with the same variety and same dose of N for growth parameters, yield attributes & yield as well as water productivity using a one-sample t-test. A significantly higher root length was observed in direct-seeded rice compared to transplanted rice in all the 3 varieties; while panicle weight did not differ with establishment methods @ 5% level of significance. Number of unfilled grains & chaffy grain% was low in direct-seeded rice of DRR Dhan-42, while it did not differ statistically for JGL-24423 at 100% N. For KNM-1638, transplanted rice recorded a significantly lower number of unfilled grains & chaffy grain percentage at both 100 & 125%N. DDSR & CFTPR recorded comparable grain yields in DRR Dhan-42 @ 100 (P = 0.22) & 125% N (P = 0.07) & in JGL-24423 @ 100% N (P = 0.18). For KNM-1638, higher grain yield was reported in transplanted rice over dry direct-seeded rice at both 100 (P = 0.01) & 125% N (P = 0.01). A significantly higher harvest index was reported by transplanted rice @ 100% N in KNM-1638 (P = 0.02), whereas it did not differ statistically for JGL-24423 & DRR Dhan-42. Drip irrigated direct-seeded rice recorded 2-2.4 times higher water productivity & 2- 3 times lower water use compared to conventionally flooded transplanted rice. There is a 57-68% saving in irrigation water in DDSR over CFTPR. It can be concluded that drip irrigated dry direct-seeded rice saves a hefty amount of irrigation water without compromising yield depending on the variety. For saving irrigation water without compensating yield, drip irrigated dry direct seeding of paddy is recommended with 100% N in JGL-24423 & DRR Dhan-42.

Keywords: Drip irrigation; dry direct seeded rice; transplanted rice; flood irrigation.

1. INTRODUCTION

The global area under rice in 2020 is 163 million hectares with a production of 769 million tonnes and productivity of 4717 kg ha^{-1}[1]. It is the most important cereal crop of India, which occupies about 22.77 per cent of the gross cropped area in the country and contributes to 40 per cent of total food grain production. Being a huge freshwater user, paddy consumes twice as much as water compared to wheat and maize. Population explosion and climate change impart considerable pressure on water resources. By 2050, there could be a 30% reduction in agricultural production due to water scarcity alone in South Asia [2].

There has been an 18% reduction in rainfall over normal rainfall in India during 2022 [1]. Ground-water extraction for irrigation has already resulted in receding water tables in many states [3]. Drying up of wells and other surface water resources, the immediate consequence of receding water table paves the way for socio-economic problems including scarcity of water for drinking, sanitation, animal husbandry & agricultural uses. So the unsustainable water use in paddy cultivation should be checked immediately to avoid the country's far-reaching socio-economic, environmental and health challenges.

This necessitates the shift from traditional flooded paddy to other alternate methods with less water consumption. Rice is a semi-aquatic crop and ponding water is not a necessity but a management tool [4-6]. Aerobic rice serves as an alternative without sacrificing much of the potential yield, while conserving a considerable proportion of irrigation water, labor and nutrients. It involves direct seeding of non-germinated seeds in a non-puddled and non-saturated soil without ponded water and maintaining soil moisture at field capacity by surface irrigation methods thus ensuring an aerated soil environment throughout the crop growing season [7]. Aerobic rice uses 3000-3500 L of water to produce 1 kg of grain with 64-88% higher water productivity than conventional puddled transplanted rice [8]. Saving of water is by way of reducing seepage, percolation, evaporation and water needed for wet land preparation.

This system is suitable for the tail end part of a large-scale surface irrigation project where water availability is insufficient to take up conventional paddy crops or where ground-water has receded to a level that makes pumping water uneconomical. Aerobic rice fits well into the purview of crop diversification into non rice-growing areas as well. It acts as an alternative to other upland crops with the added advantage of surviving unforeseen floods. Timely planting of subsequent crops is feasible for aerobic rice since it matures 7-10 days earlier than puddled transplanted rice [9]. To ensure the sustainability of rice production in water-scarce situations, aerobic rice culture needs to be practiced and popularized worldwide. Besides being a water-saving technology, aerobic rice cultivation accrues environmental protection via reduced emissions of greenhouse gases [10]. Based on trials conducted at IRRI, Philippines there was 50% reduction in methane emission in aerobic rice system when compared to low land rice production [11].

Physiological maturity is advanced in direct-seeded rice with a lesser chance of occurrence of terminal drought as transplanting injury is not encountered [12]. Farooq et al. [13] stated that direct-seeded rice had shorter crop duration than transplanted rice. This might be due to the transplantation shock and subsequent time lag encountered by transplanted rice to restart its progression [14]. Armstrong and Webb [15] pointed out that oxygenated conditions could uplift the possibility of extended root growth in rice. Singh et al. [16] observed that drip-irrigated rice recorded significantly higher root length compared to conventionally transplanted rice. Kannan & Ravikumar [17] revealed that dry direct-seeded rice recorded significantly higher grain yield (5.31 t ha^{-1}) than transplanted rice (4.95 t ha^{-1}). According to Chen et al. [18], filled grain% was significantly superior in the transplanted condition (81.8) than in the direct-seeded condition (65.8). Deokaran et al. [19] noticed higher fertility in direct-seeded rice (88%). Grain yield remained statistically non-significant under direct-seeded (4.95 t ha^{-1}) and transplanted condition (5.07t ha^{-1}). It is also critical to remember that, within a nation, direct-seeded rice performance can differ from place to place. Yield penalty was observed in the North-Western Indo-Gangetic Plains [20,21] which was not true for the eastern Indo-Gangetic Plains [22]. The variation is majorly attributed to the disparity in rainfall received [23].

The present study compares growth, yield & water use in drip irrigated dry direct-seeded rice cultivation and transplanted flooded rice culture. Although many studies have been taken up in this regard, location-specific trials incorporating the local varieties of a particular region are highly appreciated. Efforts must be made to evaluate whether drip irrigation is equally successful in rice as that of other field crops like cotton and tomato. Hence this study is highly pertinent in the state of Telangana which falls under the semi-arid tropics and largely affected by climate change induced rainfall variability.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experiment was conducted during the *kharif* seasons of 2022-23 and 2023-24 at College Farm, College of Agriculture, Rajendranangar, Hyderabad, Telangana, India. The site is geographically situated at 17°19'24.7" N–Latitude, 78°24'34.0" E–Longitude and at an altitude of 542.6 m above mean sea level. The mean maximum temperature & mean minimum temperature during the crop growing season of *kharif*, 2022 was 29.62^{0}C & 18.66^{0}C respectively. The mean maximum temperature & mean minimum temperature recorded during *Kharif*, 2023 were 30.64^{0}C & 20.67^{0}C respectively.

In *Kharif* of 2022-23, a total of 409.40 mm of rainfall was received in 23 rainy days. Total rainfall received during *kharif*, 2023-24 was 329.50 mm in 18 rainy days. Mean weekly evaporation during *Kharif*, 2022-23 ranged between 2.70 - 4.80 mm with a mean value of 3.44 mm; whereas, in *Kharif*, 2023-24 it ranged between 2.80 - 5.40 mm with a mean value of 3.94 mm.

The soil of the experimental site was sandy clay loam in texture & mildly alkaline (pH: 7.6) in reaction. The field capacity, permanent wilting point and bulk density of the soil at 0-15 cm depth were 25.15% (w/w), 14.37% (w/w) and 1.44 g cc^{-1} respectively with a maximum water holding capacity of 534.13 mm m^{-1} depth of soil.

Table 1. Soil chemical properties at 0-15 cm depth in the experimental field

Soil Chemical Properties (0-15cm)	Range	Status
Available Nitrogen	245.4 kg ha^{-1}	Low
Available Phosphorus	48.2 kg ha^{-1}	High
Available Potassium	528 kg ha^{-1}	High
Organic Carbon	0.53%	Low

2.2 Experimental Design& Cultural Practices

Drip irrigated direct-seeded rice was taken up in split-plot design with 3 replications. Main plot consists of 3 varieties, *viz*., M_1- KNM-1638, M_2-JGL-24423 & M_3- DRR Dhan-42. The sub-plot comprises 2 irrigation levels in combination with 2 nitrogen levels. S_1- Irrigation scheduled at 1.0 Epan with 100% of recommended dose of N (150 kg N ha^{-1}), S_2 -Irrigation scheduled at 1.0 Epan with 125% of recommended dose of N (187.5 kg N ha^{-1}), S_3 -Irrigation scheduled at 1.5 Epan with 100% of recommended dose of N (150 kg N ha^{-1}) & S_4 -Irrigation scheduled at 1.5 Epan with 125% of recommended dose of N (187.5 kg N ha^{-1}). Irrigation was scheduled on alternate days based on the pan evaporation value of the previous 2 days. Recommended dose of fertilizers was 150: 60: 40 kg NPK ha^{-1}. The entire dose of N & K was applied through fertigation (N through Urea & K through Potassium sulphate). Fertigation was started on 10 DAS at an interval of 7 days. Drip laterals were spaced at 80 cm, having emitters placed at 40 cm. The discharge rate of emitters was 2 Litre per hour (Lph).

An observation trial was taken up with these 3 rice varieties under transplanted condition with 100 & 125% N. Seedlings of the three varieties were raised in 3 separate nursery beds. Sprouted seeds were sown in nursery beds with a thin film of water. After 2 days water was allowed in the nursery beds and 2-3 cm water was maintained till uprooting. 28 day old seedlings were transplanted to main field.

Primary tillage was done in the main field with a tractor-mounted disc plough. Water was let in the field followed by puddling using a tractor-drawn cage wheel. The field was levelled and plots of 7.2 m length and 4.0 m width were formed. Each plot was enclosed with bunds of 30 cm width and 15 cm height. Channels of 40 cm in width were given for irrigation and drainage purposes. Seedlings were transplanted at a spacing of 20 cm x 10 cm.

A water level of 1.5 cm was maintained at the time of transplanting. The water level was gradually increased to 5 cm. Flood irrigation was given at a depth of 5 cm, 2 days after the disappearance of ponded water. Irrigation was withheld 15 days before harvest to allow uniform ripening. The entire dose of P (60 kg ha^{-1}) and K (40 kg ha^{-1}) was applied as basal before transplanting. In each variety one plot was given 100% N (150 kg N ha^{-1}) and the other plot was given 125% N (187.5 kg N ha^{-1}). Half dose of N was applied as basal followed by 25% each at tillering and panicle initiation stages.

2.3 Recording of Observations

To obtain grain yield, plants from the net plot area were harvested, sun-dried for 3 days, threshed and winnowed. Grain was weighed at 14% moisture level and expressed as kg ha^{-1}. For destructive sampling, five plants from the second outermost row in the border row were made use of. For panicle weight 5 panicles were cut randomly from the net plot area, The panicles were dried at 65^0C and weighed. The mean weight of 5 panicles was expressed in g.Chaffy grain% was obtained through the formula

$$\text{Chaffy grain \%} = \frac{\text{Number of unfilled grains per panicle}}{\text{Total number of grains per panicle}}$$

The harvest index was obtained through the formula given by Donald [24]

$$\text{Harvest index} = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Grain yield (kg ha}^{-1}) + \text{Straw yield (kg ha}^{-1})}$$

2.4 Tools of Statistical Analysis

The best-performing irrigation level under 100% N & 125% N within each variety was compared with the corresponding dose of N & variety grown under transplanted conditions using a one-sample t-test.

OP Stat software (designed and developed by the Computer Section, CCS HAU, Hissar) was used for carrying out one sample t-test.

3. RESULTS AND DISCUSSION

From the grain yield data of two years it was found that variety KNM-1638 (M_1) did not differ statistically among different sub-plot levels. So under 100 & 125% N, 1.0 Epan irrigation level was selected as the best treatments (M_1S_1 & M_1S_2) from the economic utilization of water point of view. In case of JGL-24423 (M_2) & DRR Dhan-42 (M_3), significantly higher yields were obtained at 1.5 Epan with either 100 or 125%N. So M_2S_3& M_2S_4 are selected as the best treatments for M_2 and M_3S_3 & M_3S_4 are selected as best treatments for M_3.

The best treatment under each variety was compared with conventionally flooded transplanted rice. Mean values of the 2-year data are furnished in Tables & Figure.

3.1 Root Length

All the 3 varieties of rice showed significant differences in root length under dry direct-seeded rice (DDSR) & conventionally flooded transplanted rice (CFTPR) with either 100 or 125% N. Root length observed under DDSR was significantly higher than that registered under CFTPR (Tables 2,3). Mean root lengths of M_1S_1& M_1S_2 were 10 cm & 9.9 cm respectively which were significantly higher than their corresponding flood irrigated treatments. M_2S_3 recorded mean root length of 12 cm which was significantly higher than M_2 + 100% N under flooded conditions (8.2 cm). M_2 + 125% N under flooded conditions recorded significantly lower root length (8.4 cm) than M_2S_4 (12.1). The mean root length recorded by M_3S_3 (14.9 cm) was significantly higher than M_3 + 100% N under flooded conditions. Similarly, M_3S_4 also registered significantly higher root length (14.7 cm) than M_3 + 125% N under flooded conditions (8.7 cm). Frequent aeration of soil in drip irrigation favours the fibrous root system of rice leading to longer roots [25]. Among the varieties, a longer root system was observed in DRR Dhan-42 which is highly appreciable for survival under water-limited situations [26]. A deeper root system enables plants to explore more soil volume for moisture and nutrient capture. It enables plants to capture sub-surface soil moisture as well [27]. Rajesh and Thanunathan [28] observed that a higher root length favoured increased uptake of nutrients and dry matter accumulation. In comparison to lowland conditions, rice cultivars with deeper roots and more density are far more suited to aerobic conditions [29].

Table 2. The comparison of root length (cm) in M_1S_1, M_2S_3& M_3S_3 with conventionally flooded transplanted system of M_1 +100% N, M_2 +100% N & M_3 + 100% N respectively

Treatments	Root length	Treatments	Root length	Treatments	Root length
M_1S_1 (DDSR)	10.0	M_2S_3 (DDSR)	12.0	M_3S_3 (DDSR)	14.9
M_1 +100% N (CFTPR)	7.6	M_2 +100% N (CFTPR)	8.2	M_3 +100% N (CFTPR)	8.5
t Stat	8.98	t Stat	12.26	t Stat	30.7
P(0.05)	0.01	*P*(0.05)	0.01	*P*(0.05)	0.00

Table 3. The comparison of root length (cm) in M_1S_2, M_2S_4& M_3S_4 with conventionally flooded transplanted system of M_1 +125% N, M_2 +125% N & M_3 + 125% N respectively

Treatments	Root length	Treatments	Root length	Treatments	Root length
M_1S_2 (DDSR)	9.9	M_2S_4 (DDSR)	12.1	M_3S_4 (DDSR)	14.7
M_1 +125% N (CFTPR)	7.7	M_2 +125% N (CFTPR)	8.4	M_3 +125% N (CFTPR)	8.7
t Stat	9.57	t Stat	11.85	t Stat	46.2
P(0.05)	0.01	*P*(0.05)	0.01	*P*(0.05)	0.00

Table 4. The comparison of panicle weight (g) in M_1S_1, M_2S_3& M_3S_3 with a conventionally flooded transplanted system of M_1 +100% N, M_2 +100% N & M_3 + 100% N respectively

Treatments	Panicle weight	Treatments	Panicle weight	Treatments	Panicle weight
M_1S_1 (DDSR)	3.20	M_2S_3 (DDSR)	3.76	M_3S_3 (DDSR)	4.06
M_1 +100% N (CFTPR)	3.24	M_2 +100% N (CFTPR)	3.67	M_3 +100% N (CFTPR)	4.00
t Stat	-1.39	t Stat	0.79	t Stat	0.35
P(0.05)	0.30	*P*(0.05)	0.51	*P*(0.05)	0.76

Table 5. The comparison of panicle weight (g) in M_1S_2, M_2S_4 & M_3S_4 with a conventionally flooded transplanted system of M_1 +125% N, M_2 +125% N & M_3 + 125% N respectively

Treatments	Panicle weight	Treatments	Panicle weight	Treatments	Panicle weight
M_1S_2 (DDSR)	3.26	M_2S_4 (DDSR)	3.69	M_3S_4 (DDSR)	4.17
M_1 +125% N (CFTPR)	3.31	M_2 +125% N (CFTPR)	3.73	M_3 +125% N (CFTPR)	4.06
t Stat	-0.50	t Stat	-0.46	t Stat	0.47
P(0.05)	0.67	*P*(0.05)	0.69	*P*(0.05)	0.69

Table 6. The comparison of number of unfilled grains per panicle in M_1S_1, M_2S_3 & M_3S_3 with conventionally flooded transplanted system of M_1 +100% N, M_2 +100% N & M_3 + 100% N respectively

Treatments	No. of unfilled grains	Treatments	No. of unfilled grains	Treatments	No. of unfilled grains
M_1S_1 (DDSR)	37.83	M_2S_3 (DDSR)	20.50	M_3S_3 (DDSR)	17.17
M_1 +100% N (CFTPR)	26.50	M_2 +100% N (CFTPR)	19.00	M_3 +100% N (CFTPR)	26.00
t Stat	9.71	t Stat	1.30	t Stat	-6.08
P(0.05)	0.01	*P*(0.05)	0.32	*P*(0.05)	0.03

3.2 Panicle Weight

There was no significant difference in panicle weight between the direct-seeded and transplanted conditions for any of the varieties (Tables 4 & 5). Similar observations were shared by Hemlata et al. [30]. Panicle weight was least affected by establishment methods. However, a higher panicle weight implies a greater number of spikelets per panicle, a higher number of filled grains and heavier grains, which could ultimately lead to more grain yield. DDR Dhan-42 recorded a higher panicle weight than the other two varieties, which reflected in its superior grain yield (Tables 10,11).

3.3 Number of Unfilled Grains Per Panicle

Transplanted rice of KNM-1638 (M_1) recorded a significantly lower number of unfilled grains per panicle over dry direct-seeded rice both under 100 (Table 6) & 125% N (Table 7). There was no significant difference in unfilled grains between direct-seeded (20.50) and transplanted rice (19.00) in JGL-24423 at 100% N (Table 6). However, at 125% N, transplanted rice recorded a significantly lower number of unfilled grains (14.50) than dry direct-seeded rice (23.17) (Table 7). A significantly higher number of unfilled grains per panicle was observed in M_3 + 100% N (26.00) in transplanted condition over M_3S_3 (17.17) in direct-seeded condition. At 125% N also DRR Dhan-42 recorded significantly lower number of unfilled grains under direct-seeded condition (19.00) than transplanted condition (24.00). Reduced source intensity impacts plants' source-sink relationship, which lowers yield [31].

3.4 Chaffy Grain Percentage

Significantly lower chaffy grain% was recorded under the transplanted condition in KNM-1638 both under 100% (Table 8) & 125% N (Table 9). Number of unfilled grains shows similar trend (Tables 6 & 7). This indicates the better performance of KNM-1638 under transplanted condition than direct-seeded condition. There was no significant difference in chaffy grain between direct-seeded and transplanted rice at 100% N for JGL-24423 (Table 8). But at 125% N, significantly lower chaffy grain was observed under the transplanted condition (9.93%) over the direct-seeded condition (16.03%) (Table 9). In the case of DRR Dhan-42, significantly lower chaffy grain was observed under direct-seeded conditions than under transplanted conditions both at 100 (Table 8) & 125% N (Table 9). This is due to a higher number of unfilled grains under transplanted conditions (Tables 6,7).

3.5 Grain Yield

Significantly higher grain yield was recorded under transplanted conditions for KNM-1638 (M_1) at 100 (Table 10) & 125% N (Table 11). The higher grain yield could be attributed to significantly lower chaffy grain & unfilled grains per panicle as observed earlier. The lower yield in dry direct-seeded conditions could be attributed to the reduced availability of nutrients including N, Fe & Zn combined with more loss of soil organic carbon facilitated by the aerobic soil environment [9].

In the case of JGL-24423 (M_2) at 100% N, there was no difference of statistical significance in grain yield, although CFTPR recorded a higher magnitude for grain yield (Table 10). Whereas, at 125% N, significantly higher grain yield was recorded under the transplanted condition (5388 kg ha^{-1}) than under the direct-seeded condition (4892 kg ha^{-1}) (Table 11).

Table 7. The comparison of number of unfilled grains per panicle in M_1S_2, M_2S_4 & M_3S_4 with conventionally flooded transplanted system of M_1 +125% N, M_2 +125% N & M_3 + 125% N respectively

Treatments	No. of unfilled grains	Treatments	No. of unfilled grains	Treatments	No. of unfilled grains
M_1S_2 (DDSR)	38.00	M_2S_4 (DDSR)	23.17	M_3S_4 (DDSR)	19.00
M_1 +125% N (CFTPR)	23.00	M_2 +125% N (CFTPR)	14.50	M_3 +125% N (CFTPR)	24.00
t Stat	11.92	t Stat	4.67	t Stat	-5.77
P(0.05)	0.01	*P*(0.05)	0.04	*P*(0.05)	0.03

Table 8. The comparison of chaffy grain percentage in M_1S_1, M_2S_3 & M_3S_3 with conventionally flooded transplanted system of M_1 +100% N, M_2 +100% N & M_3 + 100% N respectively

Treatments	Chaffy grain, %	Treatments	Chaffy grain, %	Treatments	Chaffy grain, %
M_1S_1 (DDSR)	26.10	M_2S_3 (DDSR)	14.42	M_3S_3 (DDSR)	12.24
M_1 +100% N (CFTPR)	16.01	M_2 +100% N (CFTPR)	13.06	M_3 +100% N (CFTPR)	18.35
t Stat	15.36	t Stat	2.14	t Stat	-5.06
P(0.05)	0.00	*P*(0.05)	0.17	*P*(0.05)	0.04

Table 9. The comparison of chaffy grain percentage in M_1S_2, M_2S_4 & M_3S_4 with conventionally flooded transplanted system of M_1 +125% N, M_2 +125% N & M_3 + 125% N respectively

Treatments	Chaffy grain, %	Treatments	Chaffy grain, %	Treatments	Chaffy grain, %
M_1S_2 (DDSR)	26.26	M_2S_4 (DDSR)	16.03	M_3S_4 (DDSR)	13.32
M_1 +125% N (CFTPR)	14.11	M_2 +125% N (CFTPR)	9.93	M_3 +125% N (CFTPR)	16.56
t Stat	17.49	t Stat	6.41	t Stat	-6.03
P(0.05)	0.00	*P*(0.05)	0.02	*P*(0.05)	0.03

Table 10. The comparison of grain yield (kg ha^{-1}) in M_1S_1, M_2S_3& M_3S_3 with conventionally flooded transplanted system of M_1 +100% N, M_2 +100% N & M_3 + 100% N respectively

Treatments	Grain yield	Treatments	Grain yield	Treatments	Grain yield
M_1S_1 (DDSR)	3334	M_2S_3 (DDSR)	4977	M_3S_3 (DDSR)	5937
M_1 +100% N (CFTPR)	4521	M_2 +100% N (CFTPR)	5246	M_3 +100% N (CFTPR)	5279
t Stat	-11.54	t Stat	-2.06	t Stat	1.75
P(0.05)	0.01	*P*(0.05)	0.18	*P*(0.05)	0.22

Table 11. The comparison of grain yield (kg ha^{-1}) in M_1S_2, M_2S_4& M_3S_4 with conventionally flooded transplanted system of M_1 +125% N, M_2 +125% N & M_3 + 125% N respectively

Treatments	Grain yield	Treatments	Grain yield	Treatments	Grain yield
M_1S_2 (DDSR)	3304	M_2S_4 (DDSR)	4892	M_3S_4 (DDSR)	5726
M_1 +125% N (CFTPR)	4678	M_2 +125% N (CFTPR)	5388	M_3 +125% N (CFTPR)	5491
t Stat	-9.99	t Stat	-13.51	t Stat	3.47
P(0.05)	0.01	*P*(0.05)	0.01	*P*(0.05)	0.07

Table 12. The comparison of harvest index in M_1S_1, M_2S_3 & M_3S_3 with conventionally flooded transplanted system of M_1 + 100% N, M_2 + 100% N & M_3 + 100% N respectively

Treatments	Harvest index	Treatments	Harvest index	Treatments	Harvest index
M_1S_1 (DDSR)	0.46	M_2S_3 (DDSR)	0.44	M_3S_3 (DDSR)	0.44
M_1 +100% N (CFTPR)	0.48	M_2 +100% N (CFTPR)	0.45	M_3 +100% N (CFTPR)	0.42
t Stat	-7.00	t Stat	-1.73	t Stat	1.89
P(0.05)	0.02	*P*(0.05)	0.23	*P*(0.05)	0.20

Table 13. The comparison of harvest index in M_1S_2, M_2S_4 & M_3S_4 with conventionally flooded transplanted system of M_1 + 125% N, M_2 + 125% N & M_3 + 125% N respectively

Treatments	Harvest index	Treatments	Harvest index	Treatments	Harvest index
M_1S_2 (DDSR)	0.44	M_2S_4 (DDSR)	0.43	M_3S_4 (DDSR)	0.43
M_1 +125% N (CFTPR)	0.48	M_2 +125% N (CFTPR)	0.45	M_3 +125% N (CFTPR)	0.42
t Stat	-3.05	t Stat	-2.50	t Stat	1.73
P(0.05)	0.09	*P*(0.05)	0.13	*P*(0.05)	0.23

There was no significant difference in grain yield between DDSR & CFTPR in DRR Dhan-42 (M_3). This is in corroboration with the findings of Tao et al*.* [32]. Optimizing the management practices in direct-seeded rice can narrow down the yield gap between direct-seeded and transplanted rice. Some researchers have projected augmented yield in direct-seeded rice than transplanted rice; while others obtained opposite results in their experiments. This variation could be seen as the result of varying environmental (soil and climate) and management factors (tillage, weed management and nitrogen input) [33]. Tripathi et al*.* [34] pointed out that if weeds are successfully managed, direct-seeded rice may be able to replace transplanted rice. According to Singh et al*.* [35], improved weed control in the TPR system may be the cause of increased grain yield. However, when constraints are handled correctly in DSR, the yield is either higher or on par with TPR [36].

3.6 Harvest Index

A significantly higher harvest index was observed in M_1 + 100% N in flooded condition (0.48) over M_1S_1 (0.46) (Table 12). This agrees with the findings of Hemlata et al*.* [30]. However, at 125%

N, there was no significant difference in harvest index between direct-seeded and transplanted rice (Table 13). This reveals that though grain yield was higher at 125% N in flooded conditions physiologically 100% N is superior to 125%N.

In the case of JGL-24423 & DRR Dhan-42, harvest index was statistically comparable for DDSR & CFTPR at both 100 & 125% N (Tables 12 & 13). Similar results were noticed by Soriano et al. [37] & Liu et al. [38]. In JGL-24423, 125% N in flooded conditions showed a lower number of unfilled grains per panicle, chaffy grain% & significantly higher grain yield than its direct-seeded counterpart. However, both treatments did not differ statistically in harvest index. This shows that direct-seeded rice is equally efficient to transplanted rice physiologically at 125% N as well. This is in line with Xu et al. [33] who pointed out that there is no discernible difference in yield between direct-seeded rice and transplanted rice as influenced by the rate of N fertilizer. Both direct-seeded and transplanted rice are highly successful in these M_2 & M_3.

3.7 Water Productivity

In all the varieties at either 100 or 125% N, water productivity was significantly higher in drip-irrigated direct-seeded rice and was significantly lower in flooded transplanted conditions (Tables 14,15). KNM-1638 & JGL-24423 recorded 2 times higher water productivity under drip irrigated direct-seeded than flood irrigated transplanted conditions. In the case of DRR Dhan-42, 2.4 times higher water productivity was observed under drip-irrigated DDSR conditions over CFTPR. Vijayakumar et al. [39] reported 1.6-1.9 times higher water productivity in aerobic rice compared to puddled transplanted rice. Water productivity tended to increase with a decrease in water input [40]. Drip irrigated direct-seeded rice used 2-3 times lower water input compared to flooded transplanted rice (Fig. 1) with meager yield differences between the both, this has resulted in higher water productivity in the former. Higher water productivity under drip-irrigated direct-seeded rice has resulted from the significantly lower water input and higher or comparable grain yields which was in corroboration with the findings of Ishfaq et al. [41]. It has been suggested that in dry zones and other water-shortage areas, water productivity takes precedence over yield or "land productivity" [42,43]. Drip irrigation increases water productivity by delivering water to the soil closer to the plant with minimal water loss. Compared to 125% N, all the varieties recorded higher water productivity under 100% N.

Table 14. The comparison of total water productivity (kg ha^{-1} mm^{-1}) in M_1S_1, M_2S_3 & M_3S_3 with conventionally flooded transplanted system of M_1 + 100% N, M_2 + 100% N & M_3 + 100% N respectively

Treatments	Water productivity	Treatments	Water productivity	Treatments	Water productivity
M_1S_1 (DDSR)	7.50	M_2S_3 (DDSR)	8.82	M_3S_3 (DDSR)	10.71
M_1 +100% N (CFTPR)	3.66	M_2 +100% N (CFTPR)	4.24	M_3 +100% N (CFTPR)	4.27
t Stat	16.72	t Stat	19.78	t Stat	9.48
P(0.05)	0.00	*P*(0.05)	0.00	*P*(0.05)	0.01

Table 15. The comparison of total water productivity (kg ha^{-1} mm^{-1}) in M_1S_2, M_2S_4 & M_3S_4 with conventionally flooded transplanted system of M_1 + 125% N, M_2 + 125% N & M_3 + 125% N respectively

Treatments	Water productivity	Treatments	Water productivity	Treatments	Water productivity
M_1S_2 (DDSR)	7.44	M_2S_4 (DDSR)	8.68	M_3S_4 (DDSR)	10.32
M_1 +125% N (CFTPR)	3.78	M_2 +125% N (CFTPR)	4.36	M_3 +125% N (CFTPR)	4.44
t Stat	11.77	t Stat	67.05	t Stat	48.51
P(0.05)	0.01	*P*(0.05)	0.00	*P*(0.05)	0.00

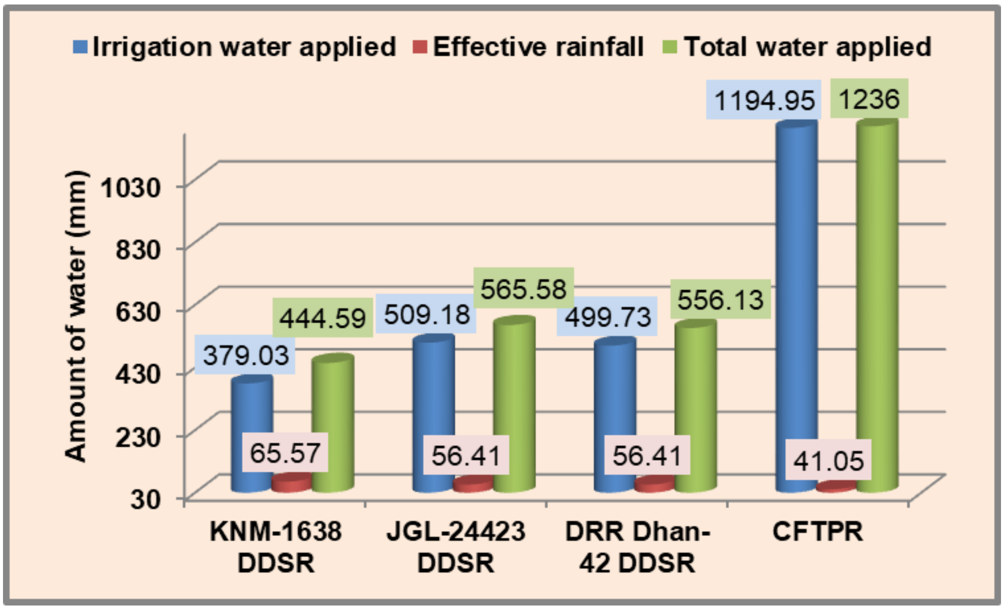

Fig. 1. Irrigation water applied (mm), Effective rainfall (mm) & total water applied (mm) in dry direct-seeded rice (DDSR) and conventionally flooded transplanted rice (CFTPR)

3.8 Irrigation Water Applied; Effective Rainfall & Total Water Applied

Data on irrigation water applied, effective rainfall & total water applied is depicted in Fig. 1. 2.3 – 3.0 times higher amount of irrigation water was applied in conventionally flooded transplanted rice (CFTPR) compared to drip irrigated dry direct-seeded rice (DDSR). Since the amount of irrigation water applied was more, effective rainfall was 1.4 - 1.6 times less in CFTPR. This is in line with the observation of Ramulu et al. [44]. Dry direct-seeded rice has saved 57 – 68% of irrigation water. The total water applied in direct-seeded rice is 726 – 791 mm less than conventionally flooded transplanted rice. They observed a 13.3% [32] & 15.5% [38] reduction in total water use in direct-seeded rice compared to transplanted rice. From the water use data, DSSR could be seen as a promising option for the water-scarce future of world agriculture.

4. CONCLUSION

Different varieties responded differently to dry direct-seeded & transplanted conditions. JGL-24423 & DRR Dhan-42 registered comparable or slightly higher yields under the dry direct-seeded conditions with 100% N compared to the transplanted conditions with a considerable saving of irrigation water. KNM-1638 did not perform well under direct-seeded conditions. Improvement in grain yield with an additional dose of N was only marginal. Therefore 100% N is advised over 125% N. For sustainable utilization of water & chemical fertilizers without compensating yield which is never more important than today, drip irrigated dry direct-seeded rice is recommended with 100% N in JGL-24423 & DRR Dhan-42.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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