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Relative Performance of Rice Varieties under Drip Irrigated Dry Direct-seeded and Flood Irrigated Transplanted Conditions

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Authors' contributions

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

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Original Research Article

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ABSTRACT

A field experiment was conducted to evaluate the performance of 3 different rice varieties (KNM-1638, JGL-24423 & DRR Dhan-42) under drip irrigated dry direct-seeded condition as well as conventionally flooded transplanted condition with 100 & 125% N. The experiment was performed in 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 RDF) in the sub-plot. An observation trial with these 3 varieties under transplanted condition with 100 & 125% N was taken up. The study was conducted during *kharif* seasons of 2022-23 and 2023-24 at College farm, College of Agriculture, Rajendranangar, Hyderabad, Telangana, India. In each variety, best performing irrigation level was found at 100% N & 125% N. Growth parameters, yield parameters & yield of best-performing treatments under dry direct-seeded (DDSR) condition was compared with conventionally flooded transplanted rice (CFTPR) with the same variety and same dose of N using one sample t-test. KNM-1638 recorded significantly higher yield at 5% level of significance under transplanted condition compared to dry direct-seeded condition both at 100% N (P=0.01) & 125% N (P=0.01). Grain yield was statistically comparable at 5% level of significance under dry direct-seeded and transplanted condition for JGL-24423 at 100% N (P= 0.18). However, at 125% N, transplanted rice recorded superior yields to that of direct-seeded rice at 5% level of significance (P = 0.01). DRR Dhan-42 registered comparable yields under direct-seeded and transplanted condition with 100 (P = 0.22) & 125% N (P = 0.07) at 5% level of significance. There observed 57-68% of saving in irrigation water in DDSR compared to CFTPR. Based on yield, economization of water and nitrogen, KNM-1638 is recommended for cultivation under transplanted condition with 100% N; whereas, JGL-24423 & DRR Dhan-42 can be successfully cultivated under dry direct-seeded condition with 100% N without yield penalty.

Keywords: Dry direct seeded rice; transplanted rice; irrigation water; grain yield; nitrogen.

1. INTRODUCTION

Among the rice-growing countries of the world, India has the largest rice acreage and ranks second in production. In India, rice is grown in about 45.77 m ha area with a production of 124.37 million tonnes and productivity of 2717 kg ha^{-1} during 2020-21 [1]. In the state of Telangana, it is grown in 4.17 m ha with the production of 21.8 million tonnes and productivity of 5240 kg ha^{-1} [2]. There is 20.5% contribution from agriculture & allied sectors to the gross value addition of the state and a source of employment to 55% of the population [2].

Traditional rice production system involves the submergence of 5-10 cm water throughout the crop season which entails the use of 3000-5000 L of water to produce 1 kg of grain [3]. In the face of industrialization and urbanization competition for fresh water from non-agricultural sectors would increase [4] which would reduce the water accessibility of the agricultural sector [5-9] directly affecting the sustainability of irrigated rice production. The increase in rice production to feed the burgeoning global population needs to be envisaged under such situations of declining water resources.

Dry direct-seeded rice (DDSR) with drip irrigation excludes ponding of water as in conventionally flooded transplanted rice (CFTR) thus saves huge amount of water. According to Ghosh et al. [10] puddling, transplanting and irrigation for flooded rice demands 2295 mm of water. Dry direct-seeded rice reduces water usage by elimination of nursery raising, puddling and ponding of water in the field [11]. Mahajan et al. [12] opined that shift from flooded rice to direct-seeded rice would increase water use efficiency by way of reducing water requirement during land preparation. It accrues an array of benefits to growers as well as environment. According to Tyagi et al. [13], direct-seeded rice imparts benefits through resource conservation (water, labour, fertilizer, energy & time), early maturity, reduced risk of unfavourable weather conditions, best fit to climate change, mitigating greenhouse gas emissions and better growth of succeeding crop fitting into various crop diversification programme. In the scenario of labour shortages and increasing labour wages, dry direct-seeded rice is a promising alternative to conventional transplanted rice with added advantage of water saving and improvement in physical condition of soil. Sharda et al. [14] opined that under water-limited situations, drip irrigated direct-seeded rice is a water cum energy saving profitable alternative to traditional puddled low land system of cultivation.

Yang et al. [15] observed that aerobic soil environment enhances tiller production in paddy along with the enhancement in development and functioning of root system. Hemlata et al. [16] reported that number of tillers m^{-2} in dry direct-seeded rice was significantly higher (706.6) than transplanted rice (534.3). Number of tillers per hill produced under aerobic rice with drip irrigation (30.69) was significantly higher than puddled transplanted rice (28.28) as well as aerobic rice under surface irrigation (26.76) [17]. Different researchers across the world have reported varied yield response of direct-seeded rice depending on location and cultivar [18]. Transplanted rice recorded 14.8% higher grain yield over dry direct-seeded rice in Telangana during kharif 2021-22 [19]. Kannan and Ravikumar [20] revealed that number of productive tillers m^{-2}, filled grains m^{-2} and grain yield were significantly superior in direct-seeded rice (278, 32272, 5.31 t ha^{-1} respectively) compared to transplanted rice (238, 27525, 4.95 t ha^{-1} respectively). Direct-seeded rice recorded higher number of panicles m^{-2} (461), grains per panicle (480) and fertility percentage (88%) over puddled transplanted rice [21]. A yield of 5-6 t ha^{-1} can be expected from aerobic rice culture with high-yielding varieties [22, 23]. Many researchers have reported only slight reduction in yield; 8% [24], 6% [25] in direct-seeded rice compared to puddled transplanted rice.

Rice is one among the most input-intensive crops of the world with fertilizers alone contributing 20-25% of the total production cost [26]. Further, they have emphasized that rice cultivation alone consumes 24.7 Mt of fertilizers and accounts for 14% of total annual fertilizer use in the world. Fertilizer industry is one among the high energy-intensive industries and non-judicious application of fertilizers poses threat to environment and questions sustainable development. Therefore an ideal nutrient management strategy needs to be introduced in rice culture, that would not only enhance productivity, profitability and nutrient use efficiency but should also be eco-friendly and environmentally sustainable. So in the present study response of 2 doses of N (100 & 125% N) is tested in direct-seeded and transplanted condition.

Success of growing rice in aerobic soil environment as in drip irrigated direct-seeded rice cultivation largely relies on choice of ideal rice varieties adapted to water limited conditions. Though the traditional upland varieties are suitable for aerobic system due to their drought tolerance, they tend to lodge under the high input levels [27]. On the other hand, the input responsive, high yielding low land varieties are severely yield limited under water scarce environment [28]. The varieties chosen for aerobic rice cultivation need to carry the high yield potential of low-land varieties with drought-tolerant characteristics of upland varieties. In the present scenario, where farmers are reluctant to take up aerobic rice cultivation, research should focus on identifying superiorly performing rice varieties under aerobic environment and the same should be introduced to farming community. So the present study was conducted to evaluate the performance of 2 popular rice varieties of Telangana *viz.*, KNM-1638 & JGL-24423 with the proven drought tolerant variety, DRR Dhan-42 at varying doses of N.

2. MATERIALS AND METHODS

2.1 Location of the Experimental Site

The experiment was conducted during *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. Meteorological parameters recorded from meteorological observatory situated at Agro Climate Research Centre, ARI, Rajendranagar were used to characterize the weather conditions prevailed during crop growing seasons. Mean maximum temperature & mean minimum temperature during crop growing season of *kharif*, 2022 was 29.6^{0}C & 18.6^{0}C respectively. Mean maximum temperature & mean minimum temperature recorded during *kharif*, 2023 were 30.6^{0}C & 20.6^{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.

Soil of the experimental site was sandy clay loam in texture & mildly alkaline (pH: 7.6) in reaction. The soil was low in available nitrogen (245.4 kg ha^{-1}), high in available phosphorus (48.2 kg ha^{-1}) and high in available potassium (528 kg ha^{-1}) with low organic carbon (0.53%).

2.2 Design of Experiment & Cultural Practices

The experiment was laid out in split plot design with 3 main and 4 sub treatments allocated randomly and replicated thrice. Three varieties were tested in the main plot;

M_1- KNM-1638
M_2- JGL-24423
M_3- DRR Dhan-42.

KNM-1638 is a high yielding short duration (120-125 days) variety with an yield potential of 7-8 t ha^{-1}. JGL-24423 is a variety suitable for both *kharif* and *rabi*. Crop duration is 125 days in *kharif* with a yield potential of 8.8-9 t ha^{-1}. DRR Dhan-42 is a high yielding short duration (120 days) drought tolerant variety suitable for upland and drought prone shallow low lands. The variety performs ideally both under direct seeding and transplanting. The variety has high yield potential (5-5.5 t ha^{-1}) and can replace other existing low yielding varieties of the same duration with a yield advantage of 0.5-1.5 t ha^{-1}.

In the sub-plot, 2 irrigation regimes were tested in combination with 2 doses of nitrogen.

S_1: Irrigation scheduled at 1.0 Epan with 100% N (150 kg N ha^{-1})

S_2: Irrigation scheduled at 1.0 Epan with 125% N (187.5 kg N ha^{-1})

S_3: Irrigation scheduled at 1.5 Epan with 100% N (150 kg N ha^{-1})

S_4: Irrigation scheduled at 1.5 Epan with 125% N (187.5 kg N ha^{-1})

Seed rate adopted was 30 kg ha^{-1}. Line sowing was done at 20 cm row spacing. Plants were later thinned out to create a plant-to-plant spacing of 10 cm. Recommended dose of fertilizer followed was 150:60:40 kg NPK ha^{-1}. Gross & net plot sizes were 28.80 m^2 & 23.04 m^2 respectively. Irrigation was scheduled on an alternate day based on pan evaporation value of the previous 2 days.

An observation trial was taken up with these 3 rice varieties under transplanted condition with 100 & 125% N. A water level of 1.5 cm was maintained at the time transplanting. Water level was gradually increased to 5 cm. Flood irrigation was given at 5 cm depth each time after disappearance of ponded water. Irrigation was withheld 15 days before harvest to allow uniform ripening. Seed rate of 20 kg ha^{-1} was used and spacing under transplanted condition was maintained at 20 cm x 10 cm. Plot size and cultural practices except irrigation management was maintained same in both direct-seeded and transplanted condition.

2.3 Recording of Observations

Five plants from the net plot area were selected randomly and tagged in each experimental plot. Observations related to yield attributes were recorded at maturity before harvest from these tagged plants. Number of tillers per m^2 & number of panicles m^{-2} were counted from the net plot area using 1 m^2 quadrant. Thousand well-filled grains were collected from net plot area at harvest. It was adjusted to 14% moisture level and weighed for the estimation of test weight.

For obtaining grain & straw yields plants from the net plot area was harvested, sun-dried for 3 days, threshed and winnowed. Grain was weighed at 14% moisture level and expressed as kg ha^{-1}.Straw from the net plot area obtained after threshing was sun dried for one week and dry weight was recorded. It was expressed in kg ha^{-1}.

2.4 Statistical Analysis

The best-performing irrigation level under 100% N & 125% N within each variety was compared with corresponding dose of N & variety grown under transplanted condition using one sample t-test at 5% level of significance.

OP Stat software (designed and developed by the Computer Section, CCS HAU, Hisar) 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 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 100 & 125%N. So M_2S_3 & M_2S_4 are selected as 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 & Fig.

3.1 Number of Tillers m^{-2}

Drip irrigated dry direct-seeded rice (DDSR) & continuously flooded transplanted rice (CFTPR) did not produce any significant difference in tiller number either at 100 (Table 1) or at 125% N (Table 2) for KNM-1638 (M_1). In the case of JGL-24423 (M_2), M_2S_3 & M_2S_4 recorded 45 & 42% higher number of tillers compared to M_2 + 100%N & M_2 + 125%N under transplanted condition respectively. So there was significant difference in tiller numbers between DDSR & CFTPR in JGL-24423. A similar trend was observable in DRR Dhan-42 (M_3) as well. M_3S_3 produced 70.8% higher number of tillers than M_3 + 100% N in flooded condition (Table 1). There was 60.1% increase in tiller production for M_3S_4 compared to M_3 + 125% N under transplanted condition (Table 2).

Tiller number was significantly higher under dry direct seeding compared to flood-irrigated transplanted rice for both JGL-24423 & DRR Dhan-42. Choudhary [29], Yang et al. [15] & Flessa and Fischer [30] revealed that aerobic soil environment promotes tiller emergence in rice. Tiller production & leaf area development superseded in DDSR over transplanted rice [31] which could be attributed to higher seedling vigour [32], which allows DDSR to achieve more light interception, increased water use efficiency [33] and early canopy cover. On the other hand, in TPR, early growth and vigour are slowed down by root damage brought on by nursery uprooting and transplanting shock. In direct seeding, a rice cultivar possessing higher seedling vigour is preferred because a crop plant with greater vigour tends to overpower the weed plant and inhibit its growth. Compared to KNM-1638, JGL-24423 & DRR Dhan-42 have registered higher number of tillers pointing towards their suitability under DDSR cultivation than KNM-1638.

3.2 Number of Panicles m^{-2}

The number of panicles m^{-2} produced by transplanted rice of KNM-1638 (M_1) was significantly higher than that produced under dry direct-seeded condition (Tables 3 & 4). Though the number of tillers was statistically comparable in direct seeding & transplanting (Tables 1 & 2), number of panicles produced under transplanted condition increased significantly. This could be attributed to higher tiller mortality encountered at direct-seeded condition; whereas, most of the tillers produced under transplanted condition were passed over to productive tillers.

Number of panicles produced in DDSR & CFTPR was comparable for both JGL-24423 (M_2) & DRR Dhan-42 (M_3) (Tables 3 & 4). The significantly lower number of tillers produced under transplanted condition in these two varieties (Tables 1 & 2) was compensated by the higher tiller mortality rate encountered in dry direct-seeded condition. Due to the prevailing aerobic environment at the vegetative stage, number of tillers produced in dry direct-seeded rice would be higher than that produced in flooded rice. However, almost half of the tillers would disappear at maturity stage in dry direct-seeded rice [34,35] due to intraspecific competition among tillers [36,37]. Tiller mortality could also be attributed to the reduced availability of plant nutrients including micronutrients in the non-flooded upland soils [38].

M_2S_3 & M_2S_4 respectively recorded 42% & 41% reduction in productive tillers over the total number of tillers produced during flowering. Although the number of tillers produced under transplanted condition was lower, most of it became productive tillers (11% reduction only). Number of productive tillers is the major decisive factor for yield [39]. Hence the difference in tiller number was compensated and comparable yields were realised.

Similar is the case of DRR Dhan-42, there observed 34 & 33% reduction in productive tillers over the number of tillers produced under flowering stage in M_3S_3 & M_3S_4 respectively. There was only a meagre reduction (7-8%) in panicle number under transplanted condition over the number of tillers produced during flowering.

Tiller mortality has nullified the supremacy of higher number of tillers produced under DDS condition. According to Soriano et al. [34], the higher number of tillers produced has got little contribution to final grain yield as the number of productive tillers did not differ significantly at maturity stage between the two establishment methods. Compared to JGL-24423, DRR Dhan-

Table 1. Comparison of number of tillers m^{-2} at flowering 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 tillers m^{-2}	Treatments	No. of tillers m^{-2}	Treatments	No. of tillers m^{-2}
M_1S_1 (DDSR)	252.17	M_2S_3(DDSR)	370.50	M_3S_3 (DDSR)	422.83
M_1 +100% N (CFTPR)	237.00	M_2 +100% N (CFTPR)	255.00	M_3 +100% N (CFTPR)	247.50
t Stat	0.73	t Stat	4.79	t Stat	6.88
P(0.05)	0.54	*P*(0.05)	0.04	*P*(0.05)	0.02

Table 2. Comparison of number of tillers m^{-2} at flowering 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 tillers m^{-2}	Treatments	No. of tillers m^{-2}	Treatments	No. of tillers m^{-2}
M_1S_2 (DDSR)	254.00	M_2S_4 (DDSR)	383.50	M_3S_4 (DDSR)	420.33
M_1 +125% N (CFTPR)	248.00	M_2 +125% N (CFTPR)	270.00	M_3 +125% N (CFTPR)	262.50
t Stat	0.62	t Stat	4.60	t Stat	6.61
P(0.05)	0.60	*P*(0.05)	0.04	*P*(0.05)	0.02

Table 3. Comparison of number of panicles m^{-2} 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 panicles m^{-2}	Treatments	No. of panicles m^{-2}	Treatments	No. of panicles m^{-2}
M_1S_1 (DDSR)	121.00	M_2S_3 (DDSR)	216.50	M_3S_3 (DDSR)	280.67
M_1 +100% N (CFTPR)	231.00	M_2 +100% N (CFTPR)	225.50	M_3 +100% N (CFTPR)	229.00
t Stat	-15.10	t Stat	-0.46	t Stat	2.70
P(0.05)	0.00	*P*(0.05)	0.69	*P*(0.05)	0.11

Table 4. Comparison of number of panicles m^{-2} 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 panicles m^{-2}	Treatments	No. of panicles m^{-2}	Treatments	No. of panicles m^{-2}
M_1S_2 (DDSR)	138.33	M_2S_4 (DDSR)	225.17	M_3S_4 (DDSR)	283.00
M_1 +125% N (CFTPR)	243.50	M_2 +125% N (CFTPR)	239.50	M_3 +125% N (CFTPR)	246.00
t Stat	-11.47	t Stat	-0.49	t Stat	3.21
P(0.05)	0.01	*P*(0.05)	0.76	*P*(0.05)	0.09

42 carried more number of tillers to the reproductive stage which shows its upper hand in dry direct-seeded situation.

3.3 Test Weight

Test weight was not affected by establishment methods. There observed no significant difference in test weight between direct-seeded and transplanted rice in any of the varieties (Tables 5 & 6). Test weight of a variety do not vary with system of cultivation as it is a genetically controlled attribute which is in line with the observations of Prathiksha et al. [40] and Mali et al. [41].

3.4 Number of Filled Grains Per Panicle

KNM-1638 (M_1) recorded significant difference in number of filled grains per panicle between direct-seeded and transplanted rice. Significantly higher number of filled grains was reported in M_1 + 100% N and M_1 + 125% N in transplanted condition over their direct-seeded counterpart (Tables 7 & 8).

For JGL-24423 (M_2), at 100% N, there was no significant difference in filled grains between DDSR & CFTPR (Table 7). But, at 125% N transplanted rice of JGL-24423 recorded significantly higher number of filled grains (131.50) than direct-seeded rice (121) (Table 8). There observed no significant difference in filled grains between direct-seeded and transplanted rice for DRR Dhan-42 (M_3) (Tables 7 & 8). A slightly higher number was observed in direct-seeded rice though statistically non-significant. Kumar et al. [42] showed that the number of grains per panicle was higher in DSR compared to transplanted rice.

Table 5. Comparison of test weight (g) 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	Test weight	Treatments	Test weight	Treatments	Test weight
M_1S_1 (DDSR)	15.73	M_2S_3 (DDSR)	23.21	M_3S_3 (DDSR)	23.57
M_1 +100% N (CFTPR)	15.61	M_2 +100% N (CFTPR)	23.15	M_3 +100% N (CFTPR)	23.40
t Stat	0.46	t Stat	0.02	t Stat	0.51
P(0.05)	0.69	*P*(0.05)	0.98	*P*(0.05)	0.66

Table 6. Comparison of test weight (g) 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	Test weight	Treatments	Test weight	Treatments	Test weight
M_1S_2 (DDSR)	15.89	M_2S_4 (DDSR)	24.11	M_3S_4 (DDSR)	22.98
M_1 +125% N (CFTPR)	15.72	M_2 +125% N (CFTPR)	23.16	M_3 +125% N (CFTPR)	23.32
t Stat	1.00	t Stat	2.46	t Stat	-3.01
P(0.05)	0.42	*P*(0.05)	0.13	*P*(0.05)	0.10

Table 7. Comparison of number of filled 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 filled grains	Treatments	No. of filled grains	Treatments	No. of filled grains
M_1S_1 (DDSR)	107.33	M_2S_3 (DDSR)	121.50	M_3S_3 (DDSR)	123.67
M_1 +100% N (CFTPR)	139.00	M_2 +100% N (CFTPR)	126.50	M_3 +100% N (CFTPR)	116.00
t Stat	-14.36	t Stat	-3.46	t Stat	2.20
P(0.05)	0.00	*P*(0.05)	0.07	*P*(0.05)	0.16

Table 8. Comparison of number of filled 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 filled grains	Treatments	No. of filled grains	Treatments	No. of filled grains
M_1S_2 (DDSR)	106.67	M_2S_4 (DDSR)	121.00	M_3S_4 (DDSR)	123.67
M_1 +125% N (CFTPR)	140.00	M_2 +125% N (CFTPR)	131.50	M_3 +125% N (CFTPR)	121.00
t Stat	-35.92	t Stat	-5.20	t Stat	2.00
P(0.05)	0.00	*P*(0.05)	0.04	*P*(0.05)	0.18

Table 9. 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

Table 10. 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

3.5 Number of Unfilled Grains Per Panicle

Transplanted rice of KNM-1638 (M1) recorded significantly lower number of unfilled grains per panicle over dry direct-seeded rice both under 100 & 125% N (Tables 9 & 10). There observed no significant difference in unfilled grains between direct-seeded (20.50) and transplanted rice (19.00) in JGL-24423 (M_2) at 100% N (Table 9). However, at 125% N, transplanted rice recorded significantly lower number of unfilled grains (14.50) than dry direct-seeded rice (23.17) (Table 10). 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 (Table 9). At 125% N also DRR Dhan-42 (M_3) recorded significantly lower number of unfilled grains under direct-seeded condition (19.00) than transplanted condition (24.00) (Table 10). In DRR Dhan-42, higher number of spikelets might have been produced in transplanted condition due to lower number of panicles (Tables 3 & 4) as the panicle number m^{-2} and the spikelet number per panicle showed a compensatory relationship [31,43]. But due to poor vegetative growth under transplanted condition as observable from the significantly lower number of tillers (Tables 1 & 2), higher proportion of the spikelets produced became chaffy. Sink activity superseded the source activity from the mid to late grain filling stages indicating transfer of assimilates from the vegetative organs to grains [44]. Reduced source intensity impacts plants' source-sink relationship, which lowers yield [45].

3.6 Grain Yield

Significantly higher grain yield was recorded under transplanted condition for KNM-1638 (M_1) at 100 (Table 11) & 125% N (Table 12). The higher grain yield could be attributed to significantly higher number of filled grains per panicle & panicles m^{-2} along with significantly lower number of unfilled grains per panicle as observed earlier. Uneven or poor crop establishment [46], higher spikelet sterility [47,48] and severe weed infestation [49,50,51] are considered to be the yield curtailing forces in dry direct-seeded condition.

In the case of JGL-24423 (M_2) at 100% N, there observed no difference of statistical significance in grain yield; although CFTPR recorded higher magnitude for grain yield (Table 11). Whereas, at 125% N, significantly higher grain yield was recorded under transplanted condition (5388 kg ha^{-1}) than under direct-seeded condition (4892 kg ha^{-1}) (Table 12). This is due to significantly higher number of filled grains and significantly lower number of unfilled grains. The performance of JGL-24423 is better under transplanted condition; nonetheless it is satisfactory under direct-seeded condition as well.

There observed no significant difference in grain yield between DDSR & CFTPR in DRR Dhan-42 (M_3) although the magnitudes were little higher under DDSR (Tables 11 & 12). DRR Dhan-42 can be successfully grown under both direct-seeded and transplanted condition. Moreover, its drought tolerant nature makes it ideal for cultivation under dry direct-seeded condition. Slightly lower grain yield under transplanted condition could be seen as a consequence of higher number of unfilled grains per panicle. Comparable yield in direct-seeded and transplanted rice was observed by Kaur & Singh [52], Farooq et al. [32] and Bhushan et al. [47].

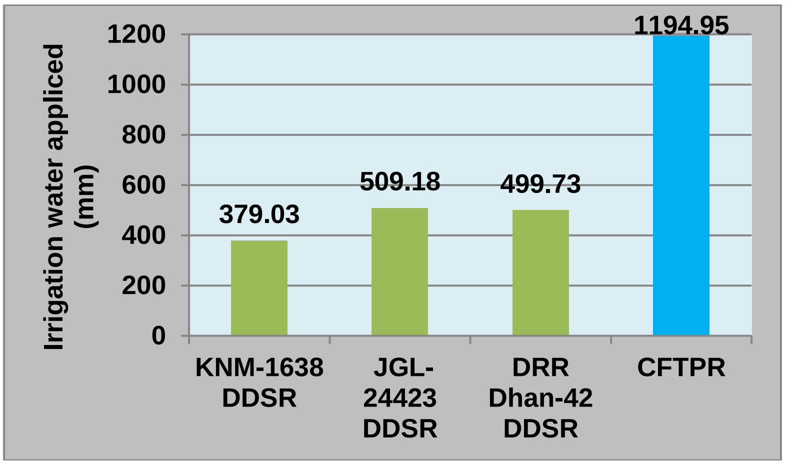

Fig. 1. Irrigation water applied (mm) in dry direct-seeded rice & conventionally flooded transplanted rice

Table 11. 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 12. 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)	
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 13. Comparison of straw 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	Straw yield	Treatments	Straw yield	Treatments	Straw yield
M_1S_1 (DDSR)	4019.81	M_2S_3 (DDSR)	6362.64	M_3S_3 (DDSR)	7703.35
M_1 +100% N (CFTPR)	4893.29	M_2 +100% N (CFTPR)	6482.71	M_3 +100% N (CFTPR)	7356.84
t Stat	-12.88	t Stat	-0.71	t Stat	1.78
P(0.05)	0.01	*P*(0.05)	0.55	*P*(0.05)	0.22

Table 14. Comparison of straw 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	Straw yield	Treatments	Straw yield	Treatments	Straw yield
M_1S_2 (DDSR)	4106.09	M_2S_4 (DDSR)	6419.99	M_3S_4 (DDSR)	7589.62
M_1 +125% N (CFTPR)	5003.05	M_2 +125% N (CFTPR)	6688.65	M_3 +125% N (CFTPR)	7426.00
t Stat	-8.58	t Stat	-2.38	t Stat	0.74
P(0.05)	0.01	*P*(0.05)	0.14	*P*(0.05)	0.54

3.7 Straw Yield

Significantly higher straw yield was recorded under transplanted condition than under direct-seeded condition in KNM-1638 (Tables 13 & 14). This could be due to higher tiller mortality under direct-seeded condition. Higher source strength as realised from higher straw yield under transplanted condition has contributed to higher grain yield in KNM-1638.

There was no significant difference in straw yield between direct-seeded and transplanted rice in case of JGL-24423 & DRR Dhan-42 at both 100 (Table 13) & 125% N (Table 14). Straw yield has followed the same trend as that of number of panicles m^{-2}. Number of panicles m^{-2} signifies the number of tillers carried over to the reproductive stage. According to Soriano et al. [34] & Lampayan et al. [35], direct-seeded rice encounters almost 50% tiller mortality at its maturity stage. More number of tillers produced under direct-seeded condition in JGL-24423 & DRR Dhan-42 underwent remarkable mortality at maturity stage leading to non-significant difference in productive tillers between direct-seeded & transplanted conditions. This has reflected in the on par straw yield registered.

3.8 Irrigation Water Applied

The amount of irrigation water applied in flood irrigated transplanted condition averages to 1194.95 mm (Fig. 1). Mean irrigation water applied in M_1 at 1.0 Epan (M_1S_1 & M_1S_2) was 379.03 mm which is 3 times lower than the amount of water applied under transplanted condition. Mean irrigation water applied in M_2 at

1.5 Epan (M_2S_3 & M_2S_4) was 509.18 mm which is 2 times lower than water input in flood irrigated transplanted condition. On an average, 499.73 mm irrigation water was applied in M_3 at 1.5 Epan (M_3S_3 & M_3S_4) which is 2 times lower than water applied in transplanted condition. Irrigation water saving under drip irrigated direct-seeded rice ranges from 57% (1.5 Epan) to 68% (1.0 Epan). Bouman and Tuong [22] & Parthasarathi et al [53] reported a water saving of 50-60% & 50% respectively under dry direct seeding over transplanted rice. 685-815 mm additional water was utilized in flooded transplanted rice with comparable yield to that of drip irrigated direct-seeded rice. The increased irrigation water needed for puddling and to compensate for natural field losses such as seepage and deep percolation is the reason for the higher water use in flooded transplanted fields [34,54]. DDSR had more irrigation events than TPR during both rice seasons, but its average water input was lower [31]. Reason could be saving of large amount of water by way of excluding puddling operations [52].

4. CONCLUSION

The 3 varieties tested responded differently under direct-seeded and transplanted conditions. KNM-1638 recorded significantly higher yield under transplanted condition than under dry direct-seeded condition especially due to higher number of panicles m^{-2}, filled grains per panicle & lower number of unfilled grains per panicle in the former. KNM-1638 is a variety suitable for transplanted condition. For the variety JGL-24423, at 100% N, there was no significant difference in grain yield between DSSR & CFTPR. However, at 125% N, CFTPR recorded superior yield to that of DDSR. JGL-24423 is more inclined to transplanted condition for growth and yield but performs satisfactorily under dry direct-seeded situation as well. For economizing irrigation water and N application dry direct-seeded crop of JGL-24423 with 100% N can be recommended. DRR Dhan-42 performs ideally under dry direct-seeded condition securing comparable yields to that of TPR. Water input in drip irrigated dry direct-seeded rice is 2-3 times lower than conventionally flooded transplanted rice with 57-68% saving of irrigation water, which makes it future of irrigated agriculture. Hence without yield penalty, DRR Dhan-42 and JGL-24423 can be cultivated under dry direct-seeded system with 100% N.

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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