Original Research Article

Drip Irrigated Dry Direct Seeded Rice: One Step Forward Towards Sustainability

ABSTRACT

Aims: A field experiment was conducted to compare the growth, yield and water use in drip irrigated aerobic rice and conventionally flooded transplanted rice.
Study design: 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.
Place and Duration of Study: The experiment was conducted during *kharif*,2022 &*kharif*, 2023 at College farm, College of Agriculture, Rajendranangar, Hyderabad, Telangana, India.
Methodology: In each variety, best performing irrigation level was found at 100% N & 125% N. 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 for growth parameters, yield attributes & yield as well as water productivity using one sample t-test.
Results: 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 significantly lower number of unfilled grains & chaffy grain% 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). 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 57-68% of saving in irrigation water in DDSR over CFTPR.
Conclusion: Drip irrigated dry direct seeded rice saves hefty amount of irrigation water without compromising yield depending on variety. For saving of 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, Root length, Water productivity, Water saving, Grain yield, Harvest index.

1. INTRODUCTION

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

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

This necessitates a 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. Aerobic rice serves as an alternative without sacrificing much of the potential yield, at the same time conserving considerable proportion of irrigation water, labour 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 through-out the crop growing season [4]. 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 [5]. Saving of water is by way of reducing seepage, percolation, evaporation and water needed for wet land preparation.

This system is suitable for tail end part of a large scale surface irrigation project where water availability is insufficient to take up conventional paddy crop or where ground water has receded to a level that makes pumping of 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 crop is feasible for aerobic rice since it matures 7-10 days earlier than puddled transplanted rice [6]. In order to ensure sustainability of rice production under water scarce situations, aerobic rice culture need to be practiced and popularized world-wide. Besides being a water saving technology, aerobic rice cultivation accrues environmental protection via reduced emission of greenhouse gases [7]. 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 [8].

Physiological maturity is advanced in direct seeded rice with lesser chance of occurrence of terminal drought as transplanting injury is not encountered [9].Farooq*et al.*[10] 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 [11].Armstrong and Webb [12] pointed out that oxygenated conditions could uplift the possibility of extended root growth in rice. Singh *et al.*[13] observed that drip irrigated rice recorded significantly higher root length compared to conventionally transplanted rice. Kannan&Ravikumar[14] 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.* [15],filled grain% was significantly superior in transplanted condition (81.8) than in direct seeded condition (65.8).Deokaran*et al.* [16] 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 [17 & 18] which was not true for the eastern Indo-Gangetic Plains [19]. The variation is majorly attributed to disparity in rainfall received [20].

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 is highly appreciated. Efforts must be made to evaluate whether drip irrigation is equally successful in rice as that of other field crop 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. MATERIAL AND METHODS

2.1 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. Mean maximum temperature & mean minimum temperature during crop growing season of *kharif*, 2022 was 29.62^{0}C & 18.66^{0}C respectively. 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.

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%).The field capacity, permanent wilting point and bulk density of the soil 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.

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. Sub-plot comprises of 2 irrigation levels in combination with 2 nitrogen levels. 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}). Irrigation was scheduled on every alternate days based on pan evaporation value of the previous 2 days. 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. Discharge rate of emitters was 2 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 tractor mounted disc plough. Water was let in the field followed by puddling using tractor drawn cage wheel. The field was levelled and plots of 7.2 m length and 4.0 m width was formed. Each plot was enclosed with bunds of 30 cm width and 15 cm height. Channels of 40 cm width were given for irrigation and drainage purpose. 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. Water level was gradually increased to 5 cm. Flood irrigation was given at 5 cm depth 2 days after disappearance of ponded water. Irrigation was withheld 15 days before harvest to allow uniform ripening. 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

For obtaining grain yield, 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}. 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, They were dried at 65^{0}C and weighed. Mean weight of 5 panicles was expressed in g.

Chaffy grain% was obtained through the formula

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

Harvest index was obtained through the formula given by Donald [21]

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

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.

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 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 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 difference 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 (Table 1 & 2). 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 condition (8.2 cm). M_2 + 125% N under flooded condition recorded significantly lower root length (8.4 cm) than M_2S_4 (12.1). Mean root length recorded by M_3S_3 (14.9 cm) was significantly higher than M_3 + 100% N under flooded condition. Similarly, M_3S_4 also registered significantly higher root length (14.7 cm) than M_3 + 125% Nunder flooded condition (8.7 cm). Frequent aeration of soil in drip irrigation favours the fibrous root system of rice leading to longer roots [22]. Among the varieties longer root system was observed in DRR Dhan-42 which is highly appreciable for survival under water limited situations [23]. Deeper root system enables plants to explore more volume of soil for moisture and nutrients capture. It enables plants to capture sub-surface soil moisture as well [24]. Rajesh and Thanunathan[25] observed that 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 [26].

3.2 Panicle weight

There was no significant difference in panicle weight between direct seeded condition and transplanted condition for any of the varieties (Table 3 & 4). Similar observations were shared byHemlata*et al.* [27]. Panicle weight was least affected by establishment methods. However, higher panicle weight implies more number of spikelets per panicle, more number of filled grains and heavier grains, which could ultimately lead to more grain yield. DDR Dhan-42 recorded higher panicle weight than the other two varieties which is reflected in its superior grain yield (Table 9 & 10).

Table 1.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 2.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 3.Comparison of panicle 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	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 4.Comparison of panicle 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	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

3.3 Number of unfilled grains per panicle

Transplanted rice of KNM-1638 (M_1) recorded significantly lower number of unfilled grains per panicle over dry direct seeded rice both under 100 (Table 5) & 125% N (Table 6). There observed no significant difference in unfilled grains between direct seeded (20.50) and transplanted rice (19.00) in JGL-24423 at 100% N (Table 5). However, at 125% N, transplanted rice recorded significantly lower number of unfilled grains (14.50) than dry direct seeded rice (23.17) (Table 6). 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 [28].

Table 5.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 6.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

3.4 Chaffy grain%

Significantly lower chaffy grain% was recorded under transplanted condition in KNM-1638 both under 100% (Table 7) & 125% N (Table 8). Number of unfilled grains shows similar trend (Table 5 & 6). 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 7). But at 125% N, significantly lower chaffy grain% was observed under transplanted condition (9.93%) over direct seeded condition (16.03%)(Table 8). In the case of DRR Dhan-42, significantly lower chaffy grain% was observed under direct seeded condition than under transplanted condition both at 100 (Table 7) & 125% N (Table 8). This is due to more number of unfilled grains under transplanted condition (Table 5 & 6).

Table 7.Comparison of chaffy grain% 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 8.Comparison of chaffy grain% 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

3.5 Grain yield

Significantly higher grain yield was recorded under transplanted condition for KNM-1638 (M_1) at 100 (Table 9) & 125% N (Table 10). The higher grain yield could be attributed to significantly lower chaffy grain% & unfilled grains per panicle as observed earlier. According to Kumar and Ladha [6], the lower yield in dry direct seeded condition could be attributed to reduced availability of nutrients including N, Fe & Zn combined with more loss of soil organic carbon facilitated by aerobic soil environment.

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 9). 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 10).

There observed 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.*[29]. 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 some 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) [30]. Tripathi*et al.*[31] pointed out that if weeds are successfully managed, direct seeded rice may be able to replace transplanted rice. According to Singh *et al.* [32], 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 [33].

Table 9.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 10.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

3.6 Harvest Index

Significantly higher harvest index was observed in M_1 + 100% N in flooded condition (0.48) over M_1S_1 (0.46) (Table 11). This is in agreement with the findings of Hemlata*et al.*[27]. However, at 125% N, there was no significant difference in harvest index between direct seeded and transplanted rice (Table 12). This reveals that though grain yield was higher at 125%N in flooded condition physiologically 100% N is superior to 125%N.

For JGL-24423 & DRR Dhan-42 harvest index was statistically comparable for DDSR & CFTPR at both 100 & 125% N (Table 11 & 12). Similar results were noticed by Soriano *et al.* [34]& Liu *et al.*[35]. In JGL-24423, 125% N in flooded condition showed lower number of unfilled grains per panicle, chaffy grain% & significantly higher grain yield than its direct seeded counterpart. However, both the 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.*[30] 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 two varieties.

Table 11.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	Treatments	Harvest	Treatments	Harvest

	index		index		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 12.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

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 condition (Table 13 & 14). KNM-1638 & JGL-24423 recorded 2 times higher water productivity under drip irrigated direct seeded condition than flood irrigated transplanted condition. In case of DRR Dhan-42, 2.4 times higher water productivity was observed under drip irrigated DDSR condition over CFTPR. Vijayakumar*et al*. [36] reported 1.6-1.9 times higher water productivity in aerobic rice compared to puddled transplanted rice. Water productivity tended to increase with decrease in water input [37]. Drip irrigated direct seeded rice used 2-3 times lower water input compared to flooded transplanted rice (Fig. 1) with meagre 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 is in corroboration with the findings of Ishfaq*et al.*[38]. It has been suggested that in dry zones and other water-shortage areas, water productivity takes precedence over yield or "land productivity" [39 & 40]. 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 13.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 14.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

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 times higher amount of irrigation water was applied in conventionally flooded transplanted rice (CFTPR) compared to drip irrigated dry direct seeded rice (DDSR). Since application of irrigation water was more, effective rainfall was 1.4-1.6 times less in CFTPR.This is in line with the observation of Ramulu*et al.* [41]. Dry direct seeded rice has saved 57 – 68% of irrigation water. The total water applied in direct seeded rice is 726 – 791 mm lesser than conventionally flooded transplanted rice. There observed 13.3% [29] & 15.5% [35]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.

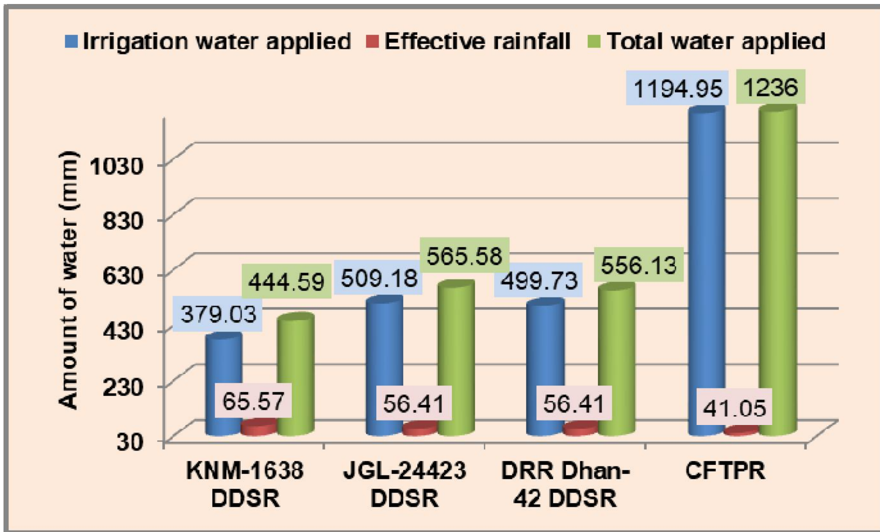

Fig. 1. Irrigation water applied (mm), Effective rainfall (mm) & total water applied (mm) in dry direct seeded rice (DDSR) and conventionally flooded transplanted rice (CFTPR)

4. CONCLUSION

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

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