

## Original Research Article

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

Formatted: Centered

### ABSTRACT

**Aims:** A field experiment ~~was was~~ conducted to compare the growth, yield, and water use in ~~drip irrigated 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 conditions~~ with 100 & 125% N was taken up.

**Place and Duration of Study:** The experiment was conducted during ~~kharif Kharif~~, 2022 & ~~kharif~~, 2023 at College ~~farm Farm~~, College of Agriculture, Rajendranagar, Hyderabad, Telangana, India.

**Methodology:** In each variety, ~~the best performing best performing~~ irrigation level was found at 100% N & 125% N. ~~Best performing 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 one sample~~ t-test.

**Results:** ~~A significantly Significantly~~ higher root length was observed in ~~direct seeded direct seeded~~ rice compared to transplanted rice in all ~~the 3 varieties varieties~~, while panicle weight did not differ with establishment methods @ 5% level of significance. ~~Number The number~~ of unfilled grains & chaffy grain% was low in ~~direct seeded 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 direct seeded~~ rice at both 100 ( $P = 0.01$ ) & 125% N ( $P = 0.01$ ). ~~Significantly 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% of~~ saving in irrigation water in DDSR over CFTPR.

**Conclusion:** Drip irrigated dry direct seeded rice saves ~~a hefty~~ amount of irrigation water without compromising yield depending on ~~the~~ 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.

Comment [Mw1]: The abstract is better to be written as one paragraph without dividing into many small paragraphs.

Comment [Mw2]: Please can you mention the quantity of repetitions?

Comment [Mw3]: I think the keywords are many and can be decreased to 5 words.

Formatted: Font: 10 pt

## 1. INTRODUCTION

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

Formatted: Font: 10 pt, Not Bold

There has been ~~an~~ 18% reduction in rainfall over normal rainfall in India during 2022 [1]. Groundwater extraction for irrigation has already resulted in receding water ~~table~~ tables 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, the immediate consequence of receding water table paves the way for socio-economic~~ problems. So the unsustainable water use in paddy cultivation should be checked immediately to avoid ~~far-reaching the country's far-reaching socio-economic, environmental, and health challenges~~ socio-economic, environmental and health challenges in the country.

~~This~~ This necessitates ~~the a~~ 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 while~~ while conserving a considerable proportion of irrigation water, ~~labour~~ 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 ~~through out~~ throughout 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 ~~the~~ the tail end part of a ~~large scale~~ large-scale surface irrigation project where water availability is insufficient to take up conventional paddy ~~crop~~ crops or where ~~ground water~~ groundwater has receded to a level that makes pumping of water uneconomical. Aerobic rice fits well into the purview of crop diversification into ~~non rice~~ 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~~ crops is feasible for aerobic rice since it matures 7-10 days earlier than puddled transplanted rice [6]. ~~In order to~~ To ensure ~~the~~ the sustainability of rice production ~~under in~~ under-in-water ~~scarce~~ water-scarce situations, aerobic rice culture ~~need~~ needs to be practiced and popularized ~~world-wide~~ worldwide. Besides being a ~~water saving~~ water-saving technology, aerobic rice cultivation accrues environmental protection via reduced ~~emission~~ emissions 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~~ direct-seeded rice with a lesser chance of occurrence of terminal drought as transplanting injury is not encountered [9]. Farooq *et al.* [10] stated that ~~direct seeded~~ direct-seeded rice had a 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~~drip-irrigated rice recorded significantly higher root length compared to conventionally transplanted rice. Kannan&Ravikumar[14] revealed that dry ~~direct seeded~~direct-seeded rice recorded significantly higher grain yield ( $5.31 \text{ t ha}^{-1}$ ) than transplanted rice ( $4.95 \text{ t ha}^{-1}$ ). According to Chen *et al.* [15],filled grain% was significantly superior in ~~the~~ transplanted condition (81.8) than in ~~the~~ direct seeded condition (65.8).Deokaran*et al.* [16] noticed higher ~~fertility%~~fertility in ~~direct seeded~~direct-seeded rice (88%). Grain yield remained statistically non-significant under direct seeded ( $4.95 \text{ t ha}^{-1}$ ) and transplanted condition ( $5.07 \text{ t ha}^{-1}$ ). 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~~-Plains[17 & 18] which was not true for the eastern Indo-Gangetic Plains [19]. The variation is majorly attributed to ~~the~~ 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~~location-specific trials incorporating the local varieties of a particular region ~~is~~-are highly appreciated. Efforts must be made to evaluate whether drip irrigation is equally successful in rice as that of ~~other field crop~~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. MATERIAL AND METHODS

### 2.1 Experimental site

The experiment was conducted during ~~the~~ *khariif* seasons of 2022-23 and 2023-24 at College ~~farm~~Farm, College of Agriculture, Rajendranagar, Hyderabad, Telangana, India. The site is geographically situated at  $17^{\circ}19'24.7''$  N-Latitude,  $78^{\circ}24'34.0''$  E-Longitude, and at an altitude of 542.6 m above mean sea level. ~~Mean~~-The mean maximum temperature & mean minimum temperature during ~~the~~ crop growing season of *khariif*, 2022 was  $29.62^{\circ}\text{C}$  &  $18.66^{\circ}\text{C}$  respectively. ~~Mean~~-The mean maximum temperature & mean minimum temperature recorded during *khariif*/*Khariif*, 2023 were  $30.64^{\circ}\text{C}$  &  $20.67^{\circ}\text{C}$  respectively.

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

~~Soil~~-The 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 ( $245.4 \text{ kg ha}^{-1}$ ), high in available phosphorus ( $48.2 \text{ kg ha}^{-1}$ ), and high in available potassium ( $528 \text{ kg ha}^{-1}$ ) 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  $1.44 \text{ g cc}^{-1}$  respectively with a maximum water holding capacity of  $534.13 \text{ mm m}^{-1}$  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<sub>1</sub>- KNM-1638, M<sub>2</sub>- JGL-24423 & M<sub>3</sub>- DRR Dhan-42. ~~Sub-plot~~The sub-plot comprises of 2 irrigation levels in combination with 2 nitrogen levels. S<sub>1</sub>-Irrigation scheduled at 1.0 Epan with 100% N ( $150 \text{ kg N ha}^{-1}$ ), S<sub>2</sub> -Irrigation scheduled at 1.0 Epan with 125% N ( $187.5 \text{ kg N ha}^{-1}$ ), S<sub>3</sub> -Irrigation scheduled at 1.5 Epan with 100% N ( $150$

**Comment [Mw4]:** What depth did you consider in calculation of the element concentrations in the soil? You can present the soil properties in a table and show depth.

**Comment [Mw5]:** What % is this? Or what portion is this? please clarify.

kg N ha<sup>-1</sup>) & S<sub>4</sub> -Irrigation scheduled at 1.5 Epan with 125% N (187.5 kg N ha<sup>-1</sup>). Irrigation was scheduled on ~~every~~ alternate days based on ~~the~~ pan evaporation value of the previous 2 days. ~~Entire-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. ~~Discharge-The discharge~~ rate of emitters was 2 Lph.

**Comment [Mw6]:** Give the reference or explanation.

**Comment [Mw7]:** What is this? Is it Litr per hour? If so please correct the writing.

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~~ tractor-mounted disc plough. Water was let in the field followed by puddling using ~~a tractor drawn~~ tractor-drawn cage wheel. The field was ~~levelled~~ leveled, and plots of 7.2 m length and 4.0 m width ~~was~~ 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 ~~purpose~~ 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. ~~Water-The water~~ level was gradually increased to 5 cm. Flood irrigation was given at ~~a~~ 5 cm depth 2 days after ~~the~~ disappearance of ponded water. Irrigation was withheld 15 days before harvest to allow uniform ripening. ~~Entire-The entire~~ dose of P (60 kg ha<sup>-1</sup>) and K (40 kg ha<sup>-1</sup>) was applied as basal before transplanting. In each variety one plot was given 100% N (150 kg N ha<sup>-1</sup>) and the other plot was given 125% N (187.5 kg N ha<sup>-1</sup>). 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~~ To obtain grain yield, plants from the net plot area ~~was-were~~ harvested, ~~sun dried~~ sun-dried for 3 days, threshed, and winnowed. Grain was weighed at 14% moisture level and expressed as kg ha<sup>-1</sup>. 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°C and weighed. ~~Mean-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 H~~ harvest index was obtained through the formula given by Donald [21]

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

### 2.4 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 ~~condition~~ using ~~a one sample 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 ~~difference~~ in root length under dry direct-seeded (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~~ ( $M_2S_4$ ) (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~~ ~~The~~ ~~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% N under flooded ~~condition~~ (8.7 cm). Frequent aeration of soil in drip irrigation ~~favours~~ the fibrous root system of rice ~~lead~~ to longer roots [22]. Among the varieties, a longer root system was observed in DRR Dhan-42 which is highly appreciable for survival under ~~water limited~~ situations [23]. A ~~Deeper~~ root system enables plants to explore more ~~soil~~ 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 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 [26].

#### 3.2 Panicle weight

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

Comment [Mw8]: The results and discussion are well presented but you could use more charts to illustrate the results.

Table 1. **The c**Comparison of root length (cm) in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with **a** conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively

Treatments	Root length	Treatments	Root length	Treatments	Root length
M <sub>1</sub> S <sub>1</sub> (DDSR)	10.0	M <sub>2</sub> S <sub>3</sub> (DDSR)	12.0	M <sub>3</sub> S <sub>3</sub> (DDSR)	14.9
M <sub>1</sub> +100% N (CFTPR)	7.6	M <sub>2</sub> +100% N (CFTPR)	8.2	M <sub>3</sub> +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. **The C**comparison of root length (cm) in M<sub>1</sub>S<sub>2</sub>, M<sub>2</sub>S<sub>4</sub> & M<sub>3</sub>S<sub>4</sub> with **a** conventionally flooded transplanted system of M<sub>1</sub> +125% N, M<sub>2</sub> +125% N & M<sub>3</sub> + 125% N respectively

Treatments	Root length	Treatments	Root length	Treatments	Root length
M <sub>1</sub> S <sub>2</sub> (DDSR)	9.9	M <sub>2</sub> S <sub>4</sub> (DDSR)	12.1	M <sub>3</sub> S <sub>4</sub> (DDSR)	14.7
M <sub>1</sub> +125% N (CFTPR)	7.7	M <sub>2</sub> +125% N (CFTPR)	8.4	M <sub>3</sub> +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. **C**The comparison of panicle weight (g) in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with **a** conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively

Treatments	Panicle weight	Treatments	Panicle weight	Treatments	Panicle weight
M <sub>1</sub> S <sub>1</sub> (DDSR)	3.20	M <sub>2</sub> S <sub>3</sub> (DDSR)	3.76	M <sub>3</sub> S <sub>3</sub> (DDSR)	4.06
M <sub>1</sub> +100% N (CFTPR)	3.24	M <sub>2</sub> +100% N (CFTPR)	3.67	M <sub>3</sub> +100% N (CFTPR)	4.00
t Stat	-1.39	t Stat	0.79	t Stat	0.35

Comment [Mw9]: Put the unit

<b>P(0.05)</b>	0.30	<b>P(0.05)</b>	0.51	<b>P(0.05)</b>	0.76
----------------	------	----------------	------	----------------	------

**Table 4.** The comparison of panicle weight (g) in M<sub>1</sub>S<sub>2</sub>, M<sub>2</sub>S<sub>4</sub> & M<sub>3</sub>S<sub>4</sub> with a conventionally flooded transplanted system of M<sub>1</sub> +125% N, M<sub>2</sub> +125% N & M<sub>3</sub> + 125% N respectively

Treatments	Panicle weight	Treatments	Panicle weight	Treatments	Panicle weight
M <sub>1</sub> S <sub>2</sub> (DDSR)	3.26	M <sub>2</sub> S <sub>4</sub> (DDSR)	3.69	M <sub>3</sub> S <sub>4</sub> (DDSR)	4.17
M <sub>1</sub> +125% N (CFTPR)	3.31	M <sub>2</sub> +125% N (CFTPR)	3.73	M <sub>3</sub> +125% N (CFTPR)	4.06
t Stat	-0.50	t Stat	-0.46	t Stat	0.47
<b>P(0.05)</b>	0.67	<b>P(0.05)</b>	0.69	<b>P(0.05)</b>	0.69

Comment [Mw10]: Unit

### 3.3 Number of unfilled grains per panicle

Transplanted rice of KNM-1638 (M<sub>1</sub>) recorded a significantly lower number of unfilled grains per panicle over dry direct-seeded rice both under 100 (Table 5) & 125% N (Table 6). There observed was 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 a significantly lower number of unfilled grains (14.50) than dry direct-seeded rice (23.17) (Table 6). Significantly a significantly higher number of unfilled grains per panicle was observed in M<sub>3</sub> + 100% N (26.00) in transplanted condition over M<sub>3</sub>S<sub>3</sub> (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 5.5.** The comparison of number of unfilled grains per panicle in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively

Treatments	No. of unfilled grains	Treatments	No. of unfilled grains	Treatments	No. of unfilled grains
M <sub>1</sub> S <sub>1</sub> (DDSR)	37.83	M <sub>2</sub> S <sub>3</sub> (DDSR)	20.50	M <sub>3</sub> S <sub>3</sub> (DDSR)	17.17

<b>M<sub>1</sub> +100% N (CFTPR)</b>	26.50	<b>M<sub>2</sub> +100% N (CFTPR)</b>	19.00	<b>M<sub>3</sub> +100% N (CFTPR)</b>	26.00
<b>t Stat</b>	9.71	<b>t Stat</b>	1.30	<b>t Stat</b>	-6.08
<b>P(0.05)</b>	0.01	<b>P(0.05)</b>	0.32	<b>P(0.05)</b>	0.03

**Table 6. The comparison of number of unfilled grains per panicle in M<sub>1</sub>S<sub>2</sub>, M<sub>2</sub>S<sub>4</sub> & M<sub>3</sub>S<sub>4</sub> with conventionally flooded transplanted system of M<sub>1</sub> +125% N, M<sub>2</sub> +125% N & M<sub>3</sub> + 125% N respectively**

Treatments	No. of unfilled grains	Treatments	No. of unfilled grains	Treatments	No. of unfilled grains
<b>M<sub>1</sub>S<sub>2</sub> (DDSR)</b>	38.00	<b>M<sub>2</sub>S<sub>4</sub> (DDSR)</b>	23.17	<b>M<sub>3</sub>S<sub>4</sub> (DDSR)</b>	19.00
<b>M<sub>1</sub> +125% N (CFTPR)</b>	23.00	<b>M<sub>2</sub> +125% N (CFTPR)</b>	14.50	<b>M<sub>3</sub> +125% N (CFTPR)</b>	24.00
<b>t Stat</b>	11.92	<b>t Stat</b>	4.67	<b>t Stat</b>	-5.77
<b>P(0.05)</b>	0.01	<b>P(0.05)</b>	0.04	<b>P(0.05)</b>	0.03

### 3.4 Chaffy grain%

Significantly lower chaffy grain% was recorded under the transplanted condition in KNM-1638 both under 100% (Table 7) & 125% N (Table 8). Number-Several of unfilled grains shows a 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 the transplanted condition (9.93%) over the 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 a more higher number of unfilled grains under transplanted condition (Table-Tables 5 & 6).

**Table 7. The comparison of chaffy grain% in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively**

Treatments	Chaffy grain %	Treatments	Chaffy grain %	Treatments	Chaffy grain %
------------	----------------	------------	----------------	------------	----------------

<b>M<sub>1</sub>S<sub>1</sub></b> <b>(DDSR)</b>	26.10	<b>M<sub>2</sub>S<sub>3</sub></b> <b>(DDSR)</b>	14.42	<b>M<sub>3</sub>S<sub>3</sub></b> <b>(DDSR)</b>	12.24
<b>M<sub>1</sub> +100% N</b> <b>(CFTPR)</b>	16.01	<b>M<sub>2</sub> +100% N</b> <b>(CFTPR)</b>	13.06	<b>M<sub>3</sub> +100% N</b> <b>(CFTPR)</b>	18.35
<b>t Stat</b>	15.36	<b>t Stat</b>	2.14	<b>t Stat</b>	-5.06
<b>P(0.05)</b>	0.00	<b>P(0.05)</b>	0.17	<b>P(0.05)</b>	0.04

Table 8. The cComparison of chaffy grain% in M<sub>1</sub>S<sub>2</sub>, M<sub>2</sub>S<sub>4</sub> & M<sub>3</sub>S<sub>4</sub> with conventionally flooded transplanted system of M<sub>1</sub> +125% N, M<sub>2</sub> +125% N & M<sub>3</sub> + 125% N respectively

Treatments	Chaffy grain <sub>1</sub> %	Treatments	Chaffy grain <sub>1</sub> %	Treatments	Chaffy grain <sub>1</sub> %
<b>M<sub>1</sub>S<sub>2</sub></b> <b>(DDSR)</b>	26.26	<b>M<sub>2</sub>S<sub>4</sub></b> <b>(DDSR)</b>	16.03	<b>M<sub>3</sub>S<sub>4</sub></b> <b>(DDSR)</b>	13.32
<b>M<sub>1</sub> +125% N</b> <b>(CFTPR)</b>	14.11	<b>M<sub>2</sub> +125% N</b> <b>(CFTPR)</b>	9.93	<b>M<sub>3</sub> +125% N</b> <b>(CFTPR)</b>	16.56
<b>t Stat</b>	17.49	<b>t Stat</b>	6.41	<b>t Stat</b>	-6.03
<b>P(0.05)</b>	0.00	<b>P(0.05)</b>	0.02	<b>P(0.05)</b>	0.03

### 3.5 Grain yield

Significantly higher grain yield was recorded under transplanted ~~condition~~ conditions for KNM-1638 (M<sub>1</sub>) 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~~ direct-seeded ~~condition~~ conditions could be attributed to the reduced availability of nutrients including N, Fe & Zn combined with more loss of soil organic carbon facilitated by an aerobic soil environment.

In the case of JGL-24423 (M<sub>2</sub>) at 100% N, ~~it was there~~ observed no difference of statistical significance in grain ~~yield~~ yield, although CFTPR recorded a higher magnitude for grain yield (Table 9). Whereas, at 125% N, significantly higher grain yield was recorded under the

Comment [Mw11]: Put the reference if available.

transplanted condition (5388 kg ha<sup>-1</sup>) than under [the](#) direct-seeded condition (4892 kg ha<sup>-1</sup>) (Table 10).

[It is](#) ~~There~~ observed no significant difference in grain yield between DDSR & CFTPR in DRR Dhan-42 (M<sub>3</sub>). This is in corroboration with the findings of Tao *et al.* [29]. ~~Optimizing~~ [Optimizing](#) the management practices in ~~direct-seeded~~ [direct-seeded](#) rice can narrow down the yield gap between ~~direct-seeded~~ [direct-seeded](#) and transplanted rice. Some researchers have projected augmented yield in ~~direct-seeded~~ [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~~ [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. [The](#) ~~C~~ comparison of grain yield (kg ha<sup>-1</sup>) in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively**

Treatments	Grain yield	Treatments	Grain yield	Treatments	Grain yield
M <sub>1</sub> S <sub>1</sub> (DDSR)	3334	M <sub>2</sub> S <sub>3</sub> (DDSR)	4977	M <sub>3</sub> S <sub>3</sub> (DDSR)	5937
M <sub>1</sub> +100% N (CFTPR)	4521	M <sub>2</sub> +100% N (CFTPR)	5246	M <sub>3</sub> +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. [The](#) ~~c~~ comparison of grain yield (kg ha<sup>-1</sup>) in M<sub>1</sub>S<sub>2</sub>, M<sub>2</sub>S<sub>4</sub> & M<sub>3</sub>S<sub>4</sub> with conventionally flooded transplanted system of M<sub>1</sub> +125% N, M<sub>2</sub> +125% N & M<sub>3</sub> + 125% N respectively**

Treatments	Grain yield	Treatments	Grain yield	Treatments	Grain yield
M <sub>1</sub> S <sub>2</sub> (DDSR)	3304	M <sub>2</sub> S <sub>4</sub> (DDSR)	4892	M <sub>3</sub> S <sub>4</sub> (DDSR)	5726
M <sub>1</sub> +125% N (CFTPR)	4678	M <sub>2</sub> +125% N (CFTPR)	5388	M <sub>3</sub> +125% N (CFTPR)	5491

<b>t Stat</b>	-9.99	<b>t Stat</b>	-13.51	<b>t Stat</b>	3.47
<b>P(0.05)</b>	0.01	<b>P(0.05)</b>	0.01	<b>P(0.05)</b>	0.07

### 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 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 conditions showed a 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 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
<b>t Stat</b>	-7.00	<b>t Stat</b>	-1.73	<b>t Stat</b>	1.89
<b>P(0.05)</b>	0.02	<b>P(0.05)</b>	0.23	<b>P(0.05)</b>	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

<b>M<sub>1</sub> +125% N (CFTPR)</b>	0.48	<b>M<sub>2</sub> +125% N (CFTPR)</b>	0.45	<b>M<sub>3</sub> +125% N (CFTPR)</b>	0.42
<b>t Stat</b>	-3.05	<b>t Stat</b>	-2.50	<b>t Stat</b>	1.73
<b>P(0.05)</b>	0.09	<b>P(0.05)</b>	0.13	<b>P(0.05)</b>	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 conditions (Tables 13 & 14). KNM-1638 & JGL-24423 recorded 2 times higher water productivity under drip irrigated direct seeded condition 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. Vijayakumaret 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 a 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 Ishfaqet 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<sup>-1</sup> mm<sup>-1</sup>) in M<sub>1</sub>S<sub>1</sub>, M<sub>2</sub>S<sub>3</sub> & M<sub>3</sub>S<sub>3</sub> with conventionally flooded transplanted system of M<sub>1</sub> +100% N, M<sub>2</sub> +100% N & M<sub>3</sub> + 100% N respectively**

Treatments	Water productivity	Treatments	Water productivity	Treatments	Water productivity
<b>M<sub>1</sub>S<sub>1</sub> (DDSR)</b>	7.50	<b>M<sub>2</sub>S<sub>3</sub> (DDSR)</b>	8.82	<b>M<sub>3</sub>S<sub>3</sub> (DDSR)</b>	10.71
<b>M<sub>1</sub> +100% N (CFTPR)</b>	3.66	<b>M<sub>2</sub> +100% N (CFTPR)</b>	4.24	<b>M<sub>3</sub> +100% N (CFTPR)</b>	4.27
<b>t Stat</b>	16.72	<b>t Stat</b>	19.78	<b>t Stat</b>	9.48
<b>P(0.05)</b>	0.00	<b>P(0.05)</b>	0.00	<b>P(0.05)</b>	0.01

**Table 14. Comparison of total water productivity ( $\text{kg ha}^{-1} \text{mm}^{-1}$ ) in  $M_1S_2$ ,  $M_2S_4$  &  $M_3S_4$  with conventionally flooded transplanted system of  $M_1 + 125\% \text{ N}$ ,  $M_2 + 125\% \text{ N}$  &  $M_3 + 125\% \text{ N}$  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
$M_1 + 125\% \text{ N}$ (CFTPR)	3.78	$M_2 + 125\% \text{ N}$ (CFTPR)	4.36	$M_3 + 125\% \text{ N}$ (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, 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 the application of irrigation water was more efficient, 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. They observed a 13.3% [29] & 15.5% [35] reduction in total water use in direct-seeded rice compared to transplanted rice. From the water use data, DDSR could be seen as a promising option for the water-scarce future of world agriculture.

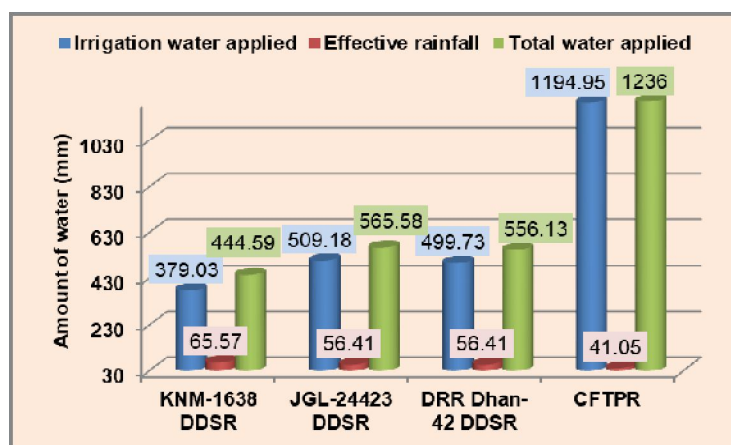


Fig. 1. Irrigation water applied (mm), Effective rainfall (mm) & total water applied (mm) in dry direct seeded rice (DDSR) and conventionally flooded transplanted rice (CFTPR)

#### 4. CONCLUSION

Different varieties responded differently to dry direct-seeding & transplanted conditions. JGL-24423 & DRR Dhan-42 registered comparable or slightly higher yields under 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 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.

#### REFERENCES

- GOI [Government of India]. Agricultural Statistics at a Glance-2022. Ministry of Agriculture & Farmers Welfare, New Delhi; 2023.
- Hossain MA, Siddique MNA. Water-a limiting resource for sustainable agriculture in Bangladesh. EC Agric. 2015; 1:124-137.
- Kukul SS. Water-saving irrigation scheduling to rice (*Oryza sativa*) in IndoGangetic plains of India. In: Huang G, Pereira LS, editors. Land and water management: decision tools and practices. vols 1 and 2. China Agricultural University, Beijing. 2004; p 83-87.
- Gandhi RV, Rudresh NS, Shivamurthy M, Hittalmani S. Performance and adoption of new aerobic rice variety MAS 946-1 (Sharada) in southern Karnataka. Karnataka J. Agric. Sci. 2012; 25(1):5-8.
- Anandan A, Pradhan SK, Singh ON. Aerobic' rice cultivation reduces water usage. 2015; The Hindu.

6. Kumar V, Ladha JK. Direct seeding of rice: recent developments and future research needs. *Adv. Agron.* 2011; 111:297–413. doi: 10.1016/B978-0-12-387689-8.00001-1.
7. Hittalmani S. MAS946-1, A new aerobic rice variety for water scarce situation. *Aerobic rice cultivation Brochure*, MAS lab, Univ. Agric. Sci., GKVK, Bangalore. 2007.
8. Vial LK. Alternate-wet-and-Dry (AWD) Rice Systems. A report for Nuffield Australia Project No.RABO 090.2007.
9. Tuong L. Studies on direct-seeding adaptability of Cambodian rice cultivars and development of cultivars with good eating quality. PhD thesis, Science of Plant and Animal Production, United Graduate School of Agricultural Science, Tokyo University of Agriculture and Technology, Japan.2008.
10. Farooq M, Basra SMA, Wahid A. Priming of field-sown rice seed enhances germination, seedling establishment, allometry and yield. *Plant Growth Regul.*2006; 49(2): 285-294.
11. Tuong TP, Pablico PP, Yamauchi M, Confesor R, Moody K. Increasing water productivity and weed suppression of wet seeded rice: Effect of water management and rice genotypes. *Experimental Agric.*2000; 36(1):71-89.
12. Armstrong W, Weeb T. A critical oxygen pressure for root extension in rice. *J Experimental Botany.*1985; 36:1573-1582.
13. Singh TC, Prajapati B, Bhardwaj AK. Effect of drip irrigation on growth and yield of direct seeded rice (*Oryza sativa* L.). *Int J Chem Stud.* 2018; 6(1):161-164.
14. Kannan VS, Ravikumar V. Development of crop geometry for drip irrigated rice cultivation. *Int J Environ Climate Change.* 2021; 11(4):97-105.
15. Chen Y, Song J, Chuan Y, Zhu G, Hong X. Comparison of yield performance and rice quality between direct-seeded and hand-transplanted rice under different nitrogen rates in Eastern China. *Afric J Agric Res.* 2020; 16(6):875-883.
16. Deokaran, Singh M, Parvez A, Mishra JS, Bhatt BP. Direct seeded rice: an option for enhancing the productivity, resource use efficiency and minimizing the production cost of the rice. *J Agric Search.* 2018; 5(3):159-162.
17. Jat ML, Gathala MK, Ladha JK, Saharawat YS, Jat AS, Kumar V, Sharma AS, Gupta R. K. Evaluation of precision land leveling and double zero-till systems in the rice-wheat rotation: Water use, productivity, profitability and soil physical properties. *Soil Tillage Res.*2009;105:112-21.
18. Saharawat YS, Singh B, Malik RK, Ladha JK, Gathala M, Jat ML, Kumar V. Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Res.*2010; 116:260–267.
19. Singh SK, Bharadwaj V, Thakur TC, Pachauri SP, Singh PP, Mishra AK. Influence of crop establishment methods on methane emission from rice fields. *Curr Sci.*2009; 97:84-89.
20. Gupta R, Seth A. A review of resource conserving technologies for suitable management of the rice-wheat cropping systems of the Indo-Gangetic Plains (IGP). *Crop Protection.*2007; 26:436-47.

21. Donald CN. In search of yield. *J Aust Institute Agric Sci.* 1962;28:1971-1978.
22. Parthasarathi T, Vanitha K, MohandassS, Vered E. Evaluation of drip irrigation system for water productivity and yield of rice. *Agron J.* 2018; 110(6):2378-2389.
23. Thakur AK, Krishna GM, Rajeeb KM, Ambast SK. Rice root growth, photosynthesis, yield and water productivity improvements through modifying cultivation practices and water management. *Agric Water Manag.* 2018; 206: 67-77.
24. Kato Y, Kamoshita A, Abe J, ImotoH, Yamagishi J. Growth of rice cultivars under upland condition with different levels of water supply. Root system development, water extraction and plant water status. *Plant Production Sci.* 2007; 10:3-13.
25. RajeshV, Thanunathan K. Effect of seedling age, number and spacing on yield and nutrient uptake of traditional Kambamchamba rice. *Madras Agric J.* 2003; 90(1-3):47-49.
26. Matsuo N, Ozawa K, Mochizuki T. Physiological and morphological traits related to water use by three rice (*Oryzasativa* L.) genotypes grown under aerobic rice systems. *Plant Soil.* 2010; 335(1): 349–361.
27. Hemlata, Joshi J, Meena SL, Rathore AL, Tandon, A, Sonit, A. Effect of crop establishment and irrigation methods on summer rice (*Oryzasativa*). *Indian J Agron.* 2018; 63(2): 168-173.
28. Peleg Z, Reguera M, Tumimbang E, Walia H, Blumwald E. Cytokinin-mediated source/sink modifications improve drought tolerance and increase grain yield in rice under water-stress. *Plant Biotechnol. J.* 2011;9:747–758. doi: 10.1111/j.1467-7652.2010.00584.x
29. Tao Y, Chen Q, Peng S, Wang W, Nie L. Lower global warming potential and higher yield of wet direct-seeded rice in Central China. *Agron Sustain Develop.* 2016; 36:24.
30. Xu L, Li X, Wang X, Xiong D, Wang F. Comparing the grain yields of direct-seeded and transplanted rice: a meta-analysis. *Agron.* 2019; 9(767): doi:10.3390/agronomy9110767.
31. Tripathi RS, RajuR, Thimmappa K. Economics of direct seeded and transplanted methods of rice production in Haryana. *Oryza.* 2014; 51(1):70-73.
32. Singh KB, Gajri PR, Arora VK. Modelling the effects of soil and water management practices on the water balance and performance of rice. *Agric Water Manag.* 2001; 49:77–95.
33. Bhushan L, Ladha JK, Gupta RK, Singh S, Tirol-Padre A, Saharawat Y, Gathala M, Pathak H. Saving of water and labor in a rice–wheat system with no-tillage and direct seeding technologies. *Agron. J.* 2007; 99: 1288–1296.
34. Soriano JB, Wani SP, Rao AN, Gajanan L, Sawargaonkar, GowdaJAC. Comparative evaluation of direct dry-seeded and transplanted rice in the dry zone of Karnataka, India. *Philippine J. of Sci.* 2018; 147(1):165-174.
35. Liu H, Hussain S, Zheng M, Peng S, Huang J, Cui, K, Nie, L. Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agron SustainDev* 2015; 35: 285–294. DOI 10.1007/s13593-014-0239-0.

36. Vijayakumar CHM, Volefi SR, Rao KV, Ramesha MS, Viratamath BC, Mishra B. Breeding for high yielding rice (*Oryzasativa* L.) varieties and hybrids adapted to aerobic (nonflooded, irrigated) conditions-I. Preliminary evaluation of a large number of improved germplasm lines. *Indian J. Genet.* 2006; 66(2):113-118.
37. Howell TA. Challenges in increasing water use efficiency in irrigated agriculture. (In) *The Proceedings of International Symposium on Water and Land Management for Sustainable Irrigated Agriculture*, Adana, Mediterranean Sea. 2006; pp. 34.
38. Ishfaq M, Akbar N, Anjum SA, Anwar-Ul-haq M. Growth, yield and water productivity of dry direct seeded rice and transplanted aromatic rice under different irrigation management regimes. *J Integrative Agric.* 2020; 19(11):2656–2673.
39. Guerra LC, Bhuiyan SI, Tuong TP, Barker R. Producing more rice with less water from irrigated systems. *SWIM Paper 5*. IWMI/IRRI, Colombo, Sri Lanka. 1998; 24p.
40. Tuong TP, Bouman BAM. Rice production in water-scarce environments, In: *Proc. Water Productivity Workshop*, 12–14 November 2001, Colombo, Sri Lanka. International Water Management Institute, Colombo, Sri Lanka. 2003.
41. Ramulu V, Reddy DM, Umadevi M. Evaluation of water saving rice production systems. *J PharmacogonPhytochem.* 2020; 9(2): 658-660.

UNDER PEER REVIEW

