

## Effect of irrigation scheduling and fertigation on nutrient and water-use efficiency in drip-irrigated direct-seeded rice (*Oryza sativa*)

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### ABSTRACT

A field experiment was conducted during the rainy (*kharif*) seasons of 2016 and 2017 at Gangavathi, Raichur, Karnataka, to study the effect of irrigation scheduling and fertigation on nitrogen and water-use efficiency of drip-irrigated direct-seeded rice (*Oryza sativa* L.) in clay soil. The experiment laid out in split-plot design with 4 irrigation scheduling based on irrigation water : cumulative pan evaporation (IW : CPE) ratios assigned to main plots and 4 drip fertigation levels were allocated in subplots and replicated thrice. Irrigation scheduling at an IW : CPE ratio of 1.50 recorded significantly higher nutrient-use efficiency, viz. nitrogen (35.2 kg/kg), phosphorus (85.4 kg/kg) and potassium (102.5 kg/kg) and but lower water-use efficiency (7.69 kg/ha-mm) and water productivity (0.61 kg/m<sup>3</sup>). Among the drip fertigation levels, drip fertigation at 75% recommended dose of nitrogen (RDN) recorded higher nitrogen-use efficiency (41.5 kg/kg). Treatment of 125% RDN resulted in higher phosphorus-use efficiency and potassium-use efficiency (84.1 and 101.0%, respectively) and water-use efficiency and water productivity (7.22 kg/ha-mm and 0.59 kg/m<sup>3</sup> respectively).

**Key words :** DSR, Fertigation, Nutrient-use efficiency, IW : CPE ratio, Water-use efficiency

Rice is one of the most ancient food crops and a primary food source for over one-third population of the world, being cultivated in 117 countries across the world and hence called as ‘global cereal’ (Santhosh, 2016). In India, it is a staple food for over two-thirds of the population and is cultivated in an area of 43.44 million ha with a production of 112.40 million tonnes and productivity of 2.70 tonnes/ha (Indiastat.com, 2017) and in Karnataka, rice occupies an area of 2.52 million ha with an annual production of 3.92 million tonnes and a productivity of 2.72 tonnes/ha (Indiastat.com, 2017).

Global water crisis is due to failure of monsoon and adoption of inefficient groundwater extraction technologies, leading to depletion of groundwater table, polluted and damaged ecosystem, which is threatening the sustainability of irrigated rice production. Further, water becomes a scarce resource due to increased demand for industrial, agricultural and domestic purposes, besides in-

creased cost on fertilizer necessitated for development and adoption of alternative agro-techniques, which help in effective and efficient utilization of these inputs. In this context, use of micro-irrigation techniques and fertigation is the only way to manage water and nutrient resources efficiently.

Direct-seeded rice (DSR) with drip irrigation can address the multifacet problems of water scarcity, weed competition and environmental pollution. When the rice cultivation is shifted from transplanted rice (TPR) to DSR, weeds pose major threat to rice production. Under such a scenario, micro-irrigation/drip irrigation plays important role in restricting weed flora apart from regular supply of required amount of moisture for DSR growth and development. Therefore, present field investigation was planned to study the nutrient and water-use efficiency as influenced by irrigation scheduling and fertigation in drip-irrigated direct-seeded rice.

### MATERIALS AND METHODS

The field experiment was conducted at Agricultural Research Station, Gangavathi, University of Agricultural Sciences (UAS), Raichur, Karnataka during the rainy (*kharif*) seasons of 2016 and 2017 at clayey soil. The soil had 0.55% organic carbon, 276.20 kg/ha nitrogen, 54.31

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kg/ha phosphorus and 265.57 kg/ha potassium, being in medium range available nutrients. The experiment was laid out in split-plot design, replicated thrice. The treatment comprised 4 irrigation scheduling based on irrigation water : cumulative pan evaporation (IW : CPE) ratios (D), viz. D<sub>1</sub>, 0.75; D<sub>2</sub>, 1.00; D<sub>3</sub>, 1.25; and D<sub>4</sub>, 1.50 assigned as main plots. Each main plot were further divided into 4 subplots, i.e. fertigation levels (F), viz. F<sub>1</sub>, 75% recommended dose of N (RDN); F<sub>2</sub>, 100% RDN; F<sub>3</sub>, 125% RDN; and F<sub>4</sub>, 100% RDF through surface application. Recommended dose of fertilizer, i.e. 150 : 60 : 50 kg/ha N: P<sub>2</sub>O<sub>5</sub> : K<sub>2</sub>O respectively in DSR.

In 2016, total rainfall received was 191.4 mm (July–December) and for the corresponding period in 2017 total rainfall received was 248.5 mm and, therefore, the effective rainfall was 134.5 mm during 2016 and 173.7 mm during 2017 with an average of 154.1 mm.

Drip-irrigation system was laid out which included pump, filter units, fertigation tank, ventury, main line and sub line for each replication and a lateral for each plot in experiment. The water source was farm pond. Water was pumped through 5.0 HP motor and it was conveyed to the main field using 90 mm of PVC pipes after filtering through sand and screen filter. From the mainline water was taken to the field through sub mains of 63 mm diameter PVC pipes. From the sub main, 12 mm laterals were fixed at a spacing of 40 cm. The emitters in the inline laterals are fixed at 40 cm. The discharge rates of emitters were 2 lph. Drip irrigation was given based on irrigation water (IW) and cumulative pan evaporation (CPE), IW: CPE ratios are taken 0.75, 1.0, 1.25 and 1.50 ratios from panicle emergence to maturity stage of DSR.

Fertigation was done through ventury system to each plot up to 100 days after sowing as per the treatment details. Fertilizer solution was filled in plastic bucket and connected with suction device of ventury. Fertigation of nitrogen was through urea fertilizer. Phosphorus and potassium were applied basal in the form of Diammonium phosphate (DAP) and muriate of potash (MoP), respectively. Fertigation schedule was started 1 week after sowing. Out of total nutrients, 50% N and the entire dose of P and K were applied basal and remaining 50% N was fertigated in 5 equal splits at 10-day intervals. Micronutrient spray was also given uniformly to all experiments. In conventional fertilizer method, fertilizers were applied in the form of urea, DAP and MoP.

The water-use efficiency was worked out from the yield of aerobic rice and the amount of water used as per Viets, (1972) and expressed in kg/ha-cm.

Total water utilized is the sum of irrigation water and effective rainfall. Effective rainfall was calculated by 70% of total rainfall (Dastane, 1974).

Nutrient-use efficiency was calculated as per the formulae given by Crasswell and Godwin, (1984) and expressed in kg/kg.

## RESULTS AND DISCUSSION

### *Irrigation water use*

Efficient use of irrigation water has always been an important factor in irrigation system. Therefore, genesis of drip irrigation happened wherever availability of water was critical and where irrigation water requirement was very high food value. Effective rainfall 70% of the actual rainfall during the cropping season was considered as effective rainfall (Sharma, 1999).

### *Total water applied (mm)*

The data on total water (Table 1) supplied which is summation of irrigation water applied and effective rainfall of respective season to different treatment combinations differed due to varying IW : CPE levels. Total water applied was lower with 0.75 IW : CPE ratio, next higher level was with 1.0 IW : CPE followed by 1.25 IW : CPE ratio, while the highest was with 1.50 IW : CPE ratio. Among the treatment combinations, the total water applied mainly followed IW : CPE ratio and not the fertigation level. It was lower with 0.75 IW : CPE ratio, medium with 1.0 and 1.25 IW : CPE ratios, while it was the highest with 1.50 IW : CPE ratio, irrespective of fertigation levels. Our results confirm those of Puspa (2006), Suresh Naik (2014) and Santhosh (2015), who reported similar results.

### *Water-use efficiency (WUE) and water productivity (WP)*

Water-use efficiency (WUE) and water productivity (WP) varied significantly due to IW : CPE ratios, fertigation levels and their interactions of both the years and on average basis as well (Table 1). Among the establishment techniques, significantly higher WUE and WP was observed with lowest irrigation or wider frequency with 0.75 IW : CPE, closely followed by 1.0 IW : CPE ratio which was at par with former treatment, while significantly lower WUE and WP were observed with 1.5 IW: CPE.

Among the fertigation practices, the highest WUE and WP were observed with 125% RDN through fertigation closely followed by application of 100% RDN through fertigation, (7.04 kg/ha mm and 0.57 kg/m<sup>3</sup>, respectively), while traditional broadcasting of recommended nitrogen level had lower WUE.

Interaction effect due to irrigation and fertigation levels revealed significantly higher WUE and WP with 0.75 IW : CPE × fertigation of 125% RDN through fertigation and all the 3 treatment combinations were at par, while significantly lower WUE and WP were recorded with 1.50 IW:

CPE × surface application of RDN. These results confirm the findings of Shekara *et al.* (2010), Rajesh (2015), Anusha (2015), Jagadish (2015) and Mishra *et al.* (2017)

#### Nitrogen-use efficiency

Nitrogen-use efficiency (NUE) of rice as influenced by IW: CPE ratios (Table 2), levels of fertigation and their interaction revealed significant differences during both the years and on average basis. An IW : CPE ratio of 1.50 recorded significantly higher NUE, closely followed by 1.25 IW : CPE ratio which was at par, while 1.00 IW: CPE and 0.75 IW : CPE ratios had lower NUE.

Among different fertigation schedules the NUE was significantly higher with 75% RDN through fertigation, followed by RDN through fertigation, while fertigation of higher levels of N (125% RDN) and traditional broadcast periodically of the recommended N resulted in the lower NUE.

Among the combinations of irrigation scheduling and fertigation levels, 1.50 IW: CPE × 75% RDN through fertigation showed significantly higher NUE, followed by 1.25 IW : CPE × 75% RDN and 1.00 IW : CPE × 75% RDN, while 0.75 IW: CPE × 125% RDN, closely followed by 1.00 IW : CPE × 125% RDN, recorded lower NUE.

#### Phosphorus-and potassium-use efficiency

Phosphorus and potassium-use efficiency of rice as influenced by irrigation and fertigation levels and their interaction revealed significant differences during both the

years on average basis.

Among the IW : CPE levels, PUE and KUE were significantly higher with higher ratio of 1.50 IW : CPE ratio, closely followed by 1.25 IW : CPE ratio and had lower in 0.75 IW : CPE ratio (74.3 and 89.1 kg/kg, respectively).

Among different fertigation schedules, 125% RDN through fertigation resulted significantly higher followed by 100% RDN through fertigation, while traditional surface broadcasting of RDN recorded the lower PUE and KUE, followed by fertigation of 75% RDN (Table 2).

Among the combinations of irrigation scheduling and fertigation levels, 1.50 IW : CPE × 125% RDN through fertigation recorded significantly higher PUE and KUE, while 0.75 IW: CPE × surface broadcasting of RDN, closely followed by 1.00 IW: CPE × surface broadcasting of RDN, recorded lower PUE and KUE respectively.

The improvement with higher IW : CPE ratio were possible owing to higher soil moisture which had facilitated to bring nutrients to soil solution. Anusha (2015) reported that, maintaining high soil-moisture content or high water potential favoured high nutrient uptake. Decrease in total NPK uptake was observed in non-fertigation treatment due to reduced soil moisture which might have reduced nitrate reductase activity, nitrification and P diffusion through the soil to root surface. found with Sharma *et al.* (2012) and Puspa (2016) also reported similar results.

#### Nutrient uptake by crop (kg/ha)

Uptake of major nutrients, viz. nitrogen, phosphorus and potassium, of rice as influenced by irrigation schedul-

**Table 1.** Total water used, water-use efficiency and water productivity as influenced by irrigation water : cumulative pan evaporation (IW : CPE) ratio and fertigation level in direct-seeded rice (DSR) (pooled data of 2 years)

Treatment	Water used (mm)	Effective rainfall (mm)	Total water used (mm)	Water use-efficiency (kg/ha-mm)	Water productivity (kg/m <sup>3</sup> )
<i>IW : CPE ratio (D)</i>					
D <sub>1</sub>	579.6	154.1	733.7	7.69	0.61
D <sub>2</sub>	646.5	154.1	800.6	7.14	0.58
D <sub>3</sub>	728.1	154.1	882.2	6.78	0.56
D <sub>4</sub>	890.2	154.1	1,044.3	5.76	0.49
SEm±	15.0	–	15.0	0.15	0.01
CD (P=0.05)	–	–	–	0.52	0.04
<i>Fertigation (F)</i>					
F <sub>1</sub>	711.1	154.1	865.2	6.69	0.55
F <sub>2</sub>	711.1	154.1	865.2	7.04	0.57
F <sub>3</sub>	711.1	154.1	865.2	7.22	0.59
F <sub>4</sub>	711.1	154.1	865.2	6.42	0.52
SEm±	–	–	–	0.14	0.01
CD (P=0.05)	–	–	–	0.40	0.03

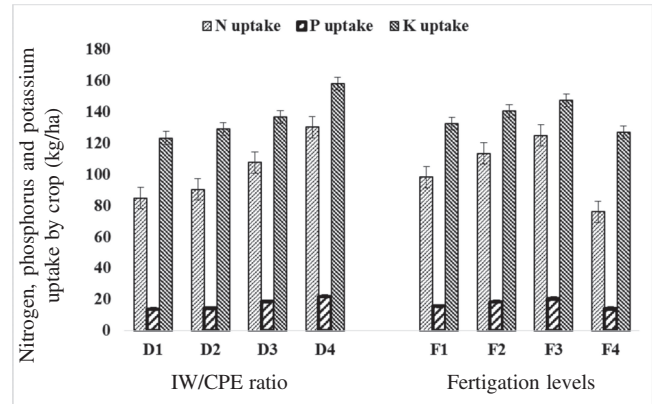
Main plots: IW: CPE ratio (D)-D<sub>1</sub>, 0.75 IW : CPE ratio; D<sub>2</sub>, 1.00 IW: CPE ratio; D<sub>3</sub>, 1.25 IW: CPE ratio; D<sub>4</sub>, 1.50 IW: CPE ratio; Sub-plots: fertigation level (F)-F<sub>1</sub>, 75% recommended dose of N (RDN); F<sub>2</sub>, 100% RDN; F<sub>3</sub>, 125% RDN; F<sub>4</sub>, 100% recommended dose of fertilizer (RDF) through surface application

ing, fertigation levels and their interaction differed significantly with different treatments. Among irrigation scheduling practices, 1.50 IW : CPE ratio revealed the highest nutrient uptake (130.3, 21.6 and 156.5 kg/ha respectively) followed by 1.25 IW : CPE, while 0.75 IW : CPE ratio resulted in the lowest nutrients uptake. Different fertigation scheduling practices revealed significantly higher nutrients uptake with 125% RDN through fertigation, followed by recommended RDF through fertigation, while traditional broadcasting practice recorded the lowest nutrients uptake (Fig. 1).

Among the treatment combinations, 1.50 IW : CPE × 125% RDN through fertigation recorded significantly higher nutrients uptake followed by 1.50 IW : CPE × 100% RDN through fertigation, while the lowest nutrients uptake among all occurred with 0.75 IW : CPE × 125% RDN through fertigation combination. This might be due to higher soil moisture which facilitated movement of nutrients into soil solution. Decrease in total NPK uptake in non-fertigation treatment was due to reduced soil moisture which might have reduced nitrate reductase activity, nitrification and diffusion from the soil to root surface. Our results are confirm those of Viswakarma *et al.* (2016) and Madane *et al.* (2017).

**Soil-available nutrients**

Soil-available nutrients (Table 2) status at the time of harvesting varied significantly due to irrigation scheduling, fertigation levels and their interaction. Among the irrigation scheduling treatments, an IW : CPE ratio of 1.5



**Fig. 1.** Nitrogen, phosphorus and potassium uptake by crop as influenced by different irrigation water : cumulative pan evaporation (IW : CPE) ratios and fertigation levels in direct-seeded rice (Details of treatments are given under Materials and Mehtods)

recorded higher soil-available nutrients (N, P and K), while lower soil-available nutrients occurred with an IW : CPE of 0.75. Soil-available nutrients status after harvesting was significantly higher with fertigation of 125% RDN, followed by RDN and both were at par, while surface broadcast application resulted in higher soil available nutrients followed by 75% RDN through surface application and both were at par.

Among the treatment combinations of IW : CPE ratios and fertigation levels, 1.50 IW : CPE ratio × 125% RDN through fertigation showed significantly higher soil-available N, P and K, closely followed by 1.25 IW : CPE ×

**Table 2.** Nutrient-use efficiency and soil available of nutrients after harvest as influenced by irrigation water : cumulative pan evaporation (IW : CPE) ratio and fertigation level in direct-seeded rice (DSR) (pooled data of 2 years)

Treatment	Use-efficiency			Soil-available nutrients (kg/ha)		
	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
<i>IW : CPE ratio (D)</i>						
D <sub>1</sub>	30.6	74.3	89.1	243.5	27.1	298.9
D <sub>2</sub>	31.6	76.8	92.2	249.3	28.4	305.4
D <sub>3</sub>	33.8	82.2	98.6	250.9	29.5	311.9
D <sub>4</sub>	35.2	85.4	102.5	254.3	30.1	314.2
SEm±	0.6	1.6	2.0	1.3	0.5	2.7
CD (P=0.05)	2.1	5.7	6.8	5.6	2.9	9.4
<i>Fertigation (F)</i>						
F <sub>1</sub>	41.5	77.9	93.5	244.2	27.6	305.8
F <sub>2</sub>	32.8	81.9	98.3	255.3	30.6	316.9
F <sub>3</sub>	26.9	84.1	101.0	259.0	31.8	325.0
F <sub>4</sub>	29.9	74.7	89.6	239.6	25.1	282.6
SEm±	0.7	1.6	1.9	2.9	0.6	2.5
CD (P=0.05)	1.9	4.7	5.6	7.6	1.7	7.2

Main plots: IW: CPE ratio (D)-D<sub>1</sub>, 0.75 IW : CPE ratio; D<sub>2</sub>, 1.00 IW : CPE ratio; D<sub>3</sub>, 1.25 IW : CPE ratio; D<sub>4</sub>, 1.50 IW : CPE ratio; Sub-plots: fertigation level (F)-F<sub>1</sub>, 75% recommended dose of N (RDN); F<sub>2</sub>, 100% RDN; F<sub>3</sub>, 125% RDN; F<sub>4</sub>, 100% recommended dose of fertilizer (RDF) through surface application

125% RDN through fertigation and were at par, while 0.75 IW : CPE × surface broadcasting of RDN recorded lower soil-available nutrients and other combinations fared intermediary.

The increase in nutrient uptake was due to better availability of nutrients and water in root zone as a result of frequent fertigation scheduling, which in turn resulted in better root activity as indicated by increased root volume and root weight. Further, it was also due to higher or increased availability of nutrients owing to fertigation besides reduction in loss of nutrients primarily due to reduced leaching of nutrients in drip fertigation as compared to soil application of fertilizer with surface irrigation. Decrease in total NPK uptake under surface irrigation and fertilizers was probably due to leaching loss of soluble form of nutrients beyond root zone (Pushpa *et al.*, 2007; Anusha, 2015).

#### Yield and yield attributes

Irrigation scheduling based on IW : CPE ratio, drip fertigation level and their combination (Table 3) had significant influence on yield and yield attributes during both the years and on pooled basis as well. Among the IW: CPE ratio, 1.50 IW : CPE ratio recorded the highest grain yield, straw yield (5,937 kg/ha) and harvest index (0.46) and yield attributes, viz. panicles/plant, panicle weight, total grains/panicle and test weight on pooled basis followed by 1.25 IW : CPE ratio and yield attributes, which were on par with each other, whereas 0.75 IW : CPE ratio recorded

significantly lower grain yield and yield attributes on pooled basis.

These improvements with 1.50 IW : CPE ratio might be owing to the continuous and uninterrupted moisture supply throughout the crop-growth period which resulted in increased moisture and besides higher cell-division and elongation. The soil water distribution under drip irrigation is vertical in the beginning but later, there will be a lateral distribution, whereas distribution remained primarily vertical under surface irrigation (Zheng *et al.*, 2004). This resulted in low soil suction, better water and nutrient uptake by plants under higher IW : CPE of drip irrigation.

Among the fertigation levels, 125% RDN and P and K basal (F<sub>3</sub>) proved superior to the other fertigation levels and recorded the highest grain yield (5,205 kg/ha), straw yield (5,897 kg/ha) and harvest index (0.46) on pooled basis, and yield attributes, viz. number of panicles/plant, panicle weight, total grains/panicle and test weight on pooled basis. The 100% RDN and P and K basal (F<sub>2</sub>) treatment was next in the order for yield and yield attributes and was comparable to the F<sub>3</sub> treatment during individual years, while 100% RDF through surface application (F<sub>4</sub>) recorded the lowest grain yield, straw yield and harvest index and yield attributes on pooled basis.

Frequent dressings of N through drip irrigation coincided well with the actual needs of crop thereby favoured growth ultimately resulting in yield improvement, while surface application failed to match the real-time demand of nutrients and hence adversely affected yield. Moreover,

**Table 3.** Influenced of irrigation water : cumulative pan evaporation (IW : CPE) ratio and fertigation level on yield and yield attributes of direct-seeded rice (pooled data of 2 years)

Treatment	Yield (kg/ha)		Harvest index	Yield attributes			
	Grain	Straw		Panicle/plant	Panicle length (cm)	Panicle weight (g)	Test-weight (g)
<i>IW : CPE ratio (D)</i>							
D <sub>1</sub>	4,431	5,074	0.47	8.01	21.47	11.45	23.08
D <sub>2</sub>	4,599	5,360	0.46	9.23	22.23	12.59	23.68
D <sub>3</sub>	4,875	5,593	0.47	10.30	22.57	12.62	24.03
D <sub>4</sub>	5,060	5,937	0.46	10.92	23.05	13.89	25.33
SEm±	58	119	–	0.36	0.49	0.45	0.21
CD (P=0.05)	200	411	0.01	1.22	1.71	1.57	0.74
<i>Fertigation (F)</i>							
F <sub>1</sub>	4,678	5,343	0.47	8.05	21.59	11.41	23.73
F <sub>2</sub>	4,914	5,651	0.46	11.05	22.82	12.97	24.27
F <sub>3</sub>	5,049	5,897	0.46	12.34	24.44	14.93	24.81
F <sub>4</sub>	4,324	5,072	0.46	7.03	20.47	11.25	23.31
SEm±	90	104	0.01	0.43	0.46	0.57	0.26
CD (P=0.05)	263	302	0.02	1.34	1.33	1.55	0.75

Main plots: IW: CPE ratio (D)-D<sub>1</sub>, 0.75 IW : CPE ratio; D<sub>2</sub>, 1.00 IW: CPE ratio; D<sub>3</sub>, 1.25 IW: CPE ratio; D<sub>4</sub>, 1.50 IW: CPE ratio; Sub-plots: fertigation level (F)-F<sub>1</sub>, 75% recommended dose of N (RDN); F<sub>2</sub>, 100% RDN; F<sub>3</sub>, 125% RDN; F<sub>4</sub>, 100% recommended dose of fertilizer (RDF) through surface application

there was increased solubility and availability of nutrients in the root zone in case of fertigation. Anusha (2015) also reported similar results.

Among the interactions, 1.50 IW : CPE ratio  $\times$  125% RDN and P and K basal ( $D_4F_3$ ) stood out among all recording higher grain yield, straw yield and harvest index on pooled basis and yield attributes, viz. panicles/plant, panicle weight, total grains/panicle and test weight on pooled basis, closely followed by 1.50 IW : CPE ratio  $\times$  100% RDN and P and K basal ( $D_4F_2$ ) and  $D_3F_3$ , which were at par with former treatment combination. The lower yield and yield attributes were recorded with 0.75 IW : CPE ratio  $\times$  100% RDF through surface application ( $D_1F_4$ ).

Improvement in yield of rice under drip fertigation was owing to the maintenance of soil near field capacity throughout the growth period in the active root zone, leading to low soil suction, which facilitated better water utilization, higher nutrients uptake and excellent maintenance of soil-water-plant relationship with higher oxygen concentration in the root zone (Santhosh, 2016).

Drip irrigation with 0.75 IW : CPE ratio is beneficial for higher grain yield and straw yield with a saving of 42.3% of irrigation water as compared to 1.50 IW : CPE ratio. Higher total nutrient-use efficiency and uptake were observed at 1.50 IW : CPE ratio than the other irrigation scheduling. Fertigation using 100 to 125% RDN is the best practice for getting higher water-use efficiency and nutrient-use efficiency and better nutrient status in soil.

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