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Research Paper

Productivity, nutrient uptake and profitability of winter season rice (*Oryza sativa*) varieties as influenced by alternate wetting-drying irrigation and nitrogen management

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ABSTRACT

A field experiment was conducted on clay loam soil at Agricultural Research Institute, Rajendranagar, Hyderabad, Telangana, during the winter (*rabi*) season of 2016–17 and 2017–18, to identify optimum scheduling of alternate wetting and drying irrigation (AWD) under different nitrogen levels on rice (*Oryza sativa* L.) varieties. The treatments consisted of 3 irrigation regimes, i.e. recommended submergence of 2 to 5 cm water level, AWD irrigation when water level falls below 3 cm from soil surface in perforated pipe, AWD irrigation when water level falls below 5 cm from soil surface in perforated pipe, as main plot treatments; 3 nitrogen levels (120, 160 and 200 kg N/ha) as subplot treatments; and 2 rice varieties ('KNM 118' and 'JGL 18047') as sub-subplot treatments laid out in a split-split plot design with 3 replications. There was no significant difference in terms of growth, yield attributes, yield, nutrient uptake and economics between rice varieties 'KNM 118' and 'JGL 18047' with continuous submergence, and alternate wetting and drying irrigation under different nitrogen levels during the winter (*rabi*) season. Irrigation maintained at recommended submergence of 2 to 5 cm water level resulted in higher growth parameters, yield attributes, grain yield (7,123 kg/ha), straw yield (8,045 kg/ha), nutrient uptake and net returns (₹57,202/ha), which were comparable with AWD irrigation when water level falls below 3 cm from soil surface in perforated pipe. Application of 200 kg N/ha ensued higher growth parameters, yield attributes, grain yield (7,086 kg/ha), straw yield (7,907 kg/ha and net returns (₹57,247/ha), which were at par with 160 kg N/ha.

Key words: Alternate wetting and drying irrigation, Economics, Grain yield, Nitrogen levels, Nutrient uptake, *Rabi* rice

Rice [*Oryza sativa* (L.)] is one of the most important staple food crops of the world. In India, Telangana is a key rice-producing state with an area of 4.244 million ha with a production of 30.47 million tonnes. A huge amount of water is used for the rice irrigation under the conventional water management in lowland rice, consuming about 70–80% of the total irrigated freshwater resources in the major part of the rice-growing regions in Asia including India. Future predictions on water scarcity limiting agricultural production have estimated that by 2025, about 15–20 million ha of Asia's irrigated rice fields will suffer from water shortage in the dry season where flooded rice is the dominant cropping system. Generally, rice consumes about 3,000–5,000 litres of water to produce 1 kg of rice, which is about 2 to 3 times more than to produce 1 kg of other cereals such as wheat or maize (Azarpour *et al*., 2011). Therefore, rice could face a threat due to water shortage and hence, there is a need to develop and adopt water-saving methods in rice cultivation, so that production and productivity levels are elevated despite the looming water crisis. However, rice is very sensitive to water stress. Attempts to reduce water in rice production may result in reduction of yield and may threaten food security. The challenge is therefore to develop socially acceptable, economically viable and environmentally sustainable novel water-management practices that allow rice production to be maintained or increased in the wake of declining water availability and an important water-saving technique is alternate wetting and drying (AWD) or intermittent irrigation where water is applied to the field a number of days after disappearance of ponded water. This means that the rice

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fields are not kept continuously submerged, but are allowed to dry intermittently during crop-growth period of rice. The underlying premise behind this irrigation technique is that the roots of the rice plant are still adequately supplied with water for some period even if there is currently no observable ponded water in the field. Singh *et al.,* (2015) reported that, in India, the AWD irrigation approach can reduce water use by about 40–70% compared to the traditional practice of continuous submergence, without a significant yield loss.

The water availability in Telangana is limited during the *rabi* season, thereby rice crop is subjected to water stress. Alternate wetting and drying (AWD) is a suitable water saving irrigation technique for such situation.

Among nutrients, nitrogen is the most important limiting element in rice growth (Jayanthi *et al*., 2007). Limitation of this nutrient in the growth period causes reduction in dry-matter accumulation which prevents grain-filling and therefore increases the number of unfilled grains. Rice shows excellent response to nitrogen application, but the recovery of applied nitrogen is quite low, being approximately 31–40%. The practice of AWD results in periodic aerobic soil conditions, stimulating sequential nitrification and denitrification losses which could consequently lead to a greater loss of applied fertilizer and soil nitrogen compared with that, under submergence conditions (Buresh and Haefele, 2010). It is reported that, nitrogen recovery of rice under AWD was significantly lower than that under submergence. Further, if an interaction exists between water-management practice and nitrogen rate, then the N input will have to be changed under AWD irrigation.

'KNM 118' and 'JGL 18047' are newly released, high-yielding rice varieties in Telangana, suited to *rabi* season. Systematic field research on agro-techniques such as nitrogen requirement for these rice varieties under AWD irrigation is however limited. In this context, the present study was undertaken to evaluate the response of new rice varieties to levels of nitrogen under AWD during *rabi* season.

MATERIALS AND METHODS

The study was conducted during the winter (*rabi*) season of 2016–17 and 2017–18 on a clay loam soil at Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana. The geographical location of the experimental site was (17°32' N, 78°39' E, 542.6 m above mean sea-level). Agro-climatologically the area is classified as Southern Telangana Agro Climatic Zone of Telangana State. According to Troll's climatic classification, it falls under semi-arid tropics.

The experiment was laid out in a split-plot design with 3 irrigation regimes [recommended submergence of 2 to 5 cm water level as per crop growth stage, alternate wetting and drying (AWD) irrigation of 3 cm when water level falls below 3 cm from soil surface in perforated pipe, AWD irrigation when water level falls below 5 cm from soil surface in perforated pipe] as main plot treatments and 3 nitrogen levels (120, 160 and 200 kg N/ha) as subplot treatments and 2 rice varieties ('KNM 118' and 'JGL 18047') as sub-subplot treatments with 3 replications. The seedlings were transplanted in the main field at 33 and 35 days age during the winter (*rabi*) season of 2016–17 and 2017–18, respectively, @ 2 seedlings/hill. A crop geometry of 15 cm × 15 cm was adopted. The recommended dose of fertilizers, viz. 120, 160 and 200 kg N (as per subplot treatments) + 26.4 kg P + 33.3 K/ha, was applied. Total nitrogen was applied in the form of urea in 3 equal splits, i.e. 1/3rd basal, 1/3rd at active tillering stage and 1/3rd at panicle-initiation stage. The entire phosphorus was applied basal in the form of single superphosphate, whereas the potassium was applied in the form of muriate of potash in 2 equal splits–as basal and top-dressing at panicle-initiation stage. The conventional flooding irrigation practice was followed in all the treatments till 15 days after transplanting (DAT) for proper establishment of the crop. The irrigation water was measured by water meter. After 15 DAT, the irrigation schedules were imposed as per the treatment requirement with the help of field water tube. In the present experiment, field water tubes were used to monitor and measure the depth of water level gradually receding in the field. When the field is flooded after each irrigation water application event, the water seeps through the perforations in to the field water tube and the water level inside the tube is the same as that of outside the tube. However, with time as the submergence depth of water level recedes, so also in the field water tube the same was monitored and measured in each field tube treatment-wise using a scale. Three different irrigation regimes based on receding water level were imposed using field tube. Irrigation was applied to re-flood the field to a water depth of 5 cm when the water level in the field tube dropped to a threshold level of about 3 or 5 cm, depending on the treatment during the base period. Irrigation was withheld 10 days ahead of harvesting. The net returns were computed by deducting the total cost of cultivation from the gross returns as per treatments. Benefit : cost ratio was calculated by dividing the net returns with the cost of cultivation for different treatments.

RESULTS AND DISCUSSION

Growth parameters

Plant height: Difference in plant height was not significant up to tillering stage on pooled mean basis. But as the crop growth advanced to panicle-initiation stage, flowering stage and at harvesting, irrigation maintained at recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) registered taller plants of 77.1, 84.3 and 92.4 cm on pooled mean basis, at these 3 stages respectively (Table 1). It could be owing to rapid growth by maintenance of adequate water supply to crop which maintained good metabolic processes that perform better nutrient mobilization, resulted in increased activity of meristematic cells and cell elongation of internodes, thus contributing to higher growth rate of stem which in turn promoted the increased plant height of rice. Ramakrishna *et al*., (2007), and Rahaman and Sinha (2013) also reported similar results.

Application of the highest nitrogen level (200 kg N/ha) (N_3) ensued in the maximum plant height at all the growth stages of crop on pooled mean basis and was significantly higher than 120 kg N/ha (N_1). High rate of nitrogen fertilizer contributed to higher availability of nitrogen which in turn resulted in stimulation of meristematic growth leading to increase in plant height at all growth stages. Nitrogen influences hyperplasia and hypertrophy and thus ultimately increases plant height. Our results confirm the findings of Meena *et al*., (2003) and Rao *et al*., (2007).

Dry-matter production: The dry-matter production was not influenced significantly by irrigation regimes at tillering stage (Table 2). Significantly higher dry-matter was produced with the recommended submergence of 2–5 cm water level as per crop growth stage (I_1) at panicle-initiation (5,822 kg/ha), flowering (12,159 kg/ha) and at harvesting (13,009 kg/ha) which was at par with AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) at panicle initiation. The increase in dry matter could be owing to rapid growth by maintenance of adequate water supply to crop which maintained good plant roots and various metabolic processes that perform better nutrient mobilization, resulted in the maximum plant height, tillers, leaf area and crop-growth rate under these treatments. Significantly higher dry matter was produced with 200 kg N/ha (N_3) at tillering (1,504 kg/ha), panicle initiation (5,780 kg/ha), flowering (12,112 kg/ha) and at harvesting (12,874 kg/ha), being at par with 160 kg N/ha (N_2). Increased nitrogen availability at higher level of nitrogen might have been responsible for profuse tillering and hence higher dry-matter production. Meena *et al*., (2003), Babu *et al*., (2013) and Ghanshyam (2016) also obtained similar results.

Yield attributes

Number of panicles: Irrigation maintained at the recommended submergence of 2 to 5 cm water level as per crop growth stage (I_1) evolved higher number of panicles/m^2 (256.3) and it was at par with AWD irrigation of 5 cm when water level drops to 3 cm in water tube (I_2) (Table 3). The reduction in number of panicles/m^2 with AWD irrigation of 5 cm when water level drops to 5 cm in water tube (I_3) compared with recommended submergence of 2 to

Table 1. Effect of alternate wetting and drying irrigation, nitrogen levels and varieties on plant height (cm) of rice during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Tillering			Panicle initiation			Flowering			Harvesting		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)												
I_1	37.3	39.7	38.5	75.2	79.0	77.1	84.0	84.6	84.3	92.9	91.7	92.4
I_2	34.3	38.7	36.5	74.4	78.0	76.2	83.0	83.5	83.2	92.2	90.2	91.2
I_3	33.5	37.1	35.3	68.8	72.8	70.8	75.2	75.4	75.3	84.1	87.6	85.8
SEm±	1.27	1.15	1.19	0.46	0.50	0.41	0.37	0.43	0.40	0.66	0.64	0.59
CD (P=0.05)	NS	NS	NS	1.3	1.4	1.1	1.1	1.2	1.1	1.8	1.8	1.7
Nitrogen (N)												
N_1, 120 kg/ha	34.1	37.8	35.9	72.0	75.7	73.8	80.0	80.4	80.2	88.7	89.3	89.0
N_2, 160 kg/ha	34.9	38.4	36.6	72.9	76.8	74.9	80.8	81.3	81.1	90.1	90.0	90.0
N_3, 200 kg/ha	36.1	39.2	37.6	73.4	77.4	75.4	81.4	81.9	81.6	90.6	90.2	90.4
SEm±	0.60	0.50	0.53	0.26	0.33	0.25	0.33	0.33	0.33	0.34	0.46	0.37
CD (P=0.05)	1.3	1.1	1.2	0.6	0.7	0.6	0.7	0.7	0.7	0.8	1.0	0.8
Varieties (V)												
V_1, ' KNM 118'	35.4	39.0	37.2	72.9	76.4	74.7	80.9	81.4	81.2	89.9	89.9	89.9
V_2, 'JGL 18047'	34.7	38.0	36.3	72.6	76.9	74.7	80.6	81.0	80.7	89.7	89.7	89.7
SEm±	0.73	0.56	0.63	0.25	0.24	0.23	0.19	0.18	0.18	0.2	0.30	0.24
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

Table 2. Dry-matter production (kg/ha) of rice as influenced by alternate wetting and drying irrigation, nitrogen levels and varieties during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Dry-matter production (kg/ha)											
	Tillering			Panicle initiation			Flowering			Harvesting		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)												
I_1	1,447	1,542	1,494	5,803	5,842	5,822	12,061	12,257	12,159	12,948	13,073	13,009
I_2	1,422	1,545	1,483	5,739	5,785	5,764	12,005	12,189	12,097	12,832	12,989	12,900
I_3	1,397	1,518	1,457	5,640	5,721	5,681	11,802	12,027	11,915	12,584	12,586	12,590
SEm±	14.3	12.3	12.4	25.2	22.3	21.5	50.8	51.1	49.3	55.3	49.5	45.2
CD (P=0.05)	NS	NS	NS	70	62	60	141	142	137	153	137	126
Nitrogen (N)												
N_1, 120 kg/ha	1,402	1,507	1,454	5,712	5,748	5,730	11,914	12,102	12,008	12,744	12,820	12,771
N_2, 160 kg/ha	1,417	1,536	1,476	5,724	5,786	5,755	11,936	12,166	12,051	12,789	12,895	12,854
N_3, 200 kg/ha	1,447	1,562	1,504	5,746	5,814	5,780	12,019	12,205	12,112	12,832	12,932	12,874
SEm±	14.6	14.0	10.2	11.1	13.1	9.2	38.8	35.6	35.5	24.1	27.6	16.9
CD (P=0.05)	32	31	28	24	29	26	85	78	77	53	60	37
Varieties (V)												
V_1, 'KNM 118'	1,425	1,538	1,481	5,733	5,783	5,758	11,973	12,162	12,067	12,809	12,898	12,844
V_2, 'JGL 18047'	1,419	1,532	1,475	5,722	5,782	5,752	11,939	12,154	12,046	12,768	12,868	12,822
SEm±	9.5	8.6	5.6	16.4	8.3	10.3	32.4	32.8	30.7	21.5	15.2	12.3
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

5 cm water level as per crop growth stage (I_1) and AWD irrigation of 5 cm when water level drops to 3 cm in water tube (I_2) was 4.86 and 2.45%. Reasons for lower number of panicles/m^2 was due to the fact that, plants had suffered from moisture stress. Hence plants were unable to extract sufficient water and nutrients under moisture-deficit conditions which ultimately led to poor growth and lesser number of tillers. Our results support the findings of Rahaman and Sinha (2013).

Maximum number of panicle m^2 was recorded with application of 200 kg N/ha (N_3) (256.1) and was at par with application of 160 kg N/ha (N_2).

Panicle weight (g): Irrigation maintained at recommended submergence of 2 to 5 cm water level as per crop growth stage (I_1) resulted in higher panicle weight (16.61 g) being at par with AWD irrigation of 5 cm when water level drops to 3 cm in water tube (I_2) (Table 3). It could be because of better growth by maintenance of adequate water supply to crop which maintained good root-system and various metabolic processes that perform better nutrient mobilization, which resulted in maximum panicle weight. This is in harmony with the observations of Azarpour *et al*., (2011) and Rahaman and Sinha (2013).

Significantly higher panicle weight was recorded with application of 200 kg N/ha (N_3) (16.52 g) which was at par with application of 160 kg N/ha (N_2) (16.42 g) and both were significantly superior to application of 120 kg N/ha (N_1). This could be owing required amount of nitrogen application to crop based on crop demand thus led to better dry-matter partitioning.

Grain and straw yield of rice: Irrigation maintained at recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) ensued significantly higher grain yield (7,123 kg/ha) and it was at par with AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) but both of these treatments resulted in significantly superior grain yield to AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe (I_3) (Table 4). The enhancement in grain yield in the recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) and AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) might be owing to favourable vegetative growth and development, as it received adequate and sufficient moisture in proper amount and at critical stages during entire period of crop-growth since water plays a vital role in the carbohydrate metabolism, protein synthesis, cell-division, cell enlargement and partitioning of photosynthates to sink for improved development of growth traits.

The maximum grain yield was obtained with the application of 200 kg N/ha (N_3) (7,086 kg/ha) and was at par

Table 3. Effect of alternate wetting and drying irrigation, nitrogen levels and varieties on panicles, panicle weight of rice during winter season (2016–17, 2017–18 and pooled means)

Treatment	Panicles (no./m^2)			Panicle weight (g)		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)						
I_1	249.1	263.6	256.3	16.50	16.73	16.61
I_2	243.4	257.4	250.4	16.27	16.50	16.38
I_3	237.6	251.3	244.4	15.94	16.24	16.09
SEm±	2.29	2.37	2.25	0.12	0.09	0.11
CD (P=0.05)	6.4	6.6	6.2	0.34	0.27	0.30
Nitrogen (N)						
N_1, 120 kg/ha	236.6	250.5	243.5	16.02	16.27	16.15
N_2, 160 kg/ha	244.6	258.4	251.5	16.32	16.52	16.42
N_3, 200 kg/ha	248.9	263.4	256.1	16.36	16.68	16.52
SEm±	2.48	2.31	2.23	0.08	0.09	0.08
CD (P=0.05)	5.4	5.1	4.9	0.17	0.19	0.18
Varieties (V)						
V_1, 'KNM 118'	244.4	258.4	251.4	16.32	16.59	16.45
V_2, 'JGL 18047'	242.3	256.4	249.3	16.15	16.39	16.27
SEm±	1.33	1.26	1.10	0.08	0.09	0.08
CD (P=0.05)	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

Table 4. Influence of alternate wetting and drying irrigation, nitrogen levels and varieties on grain yield (kg/ha), straw yield (kg/ha) and harvest index (%) of rice during (2016–17, 2017–18 and pooled means)

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Harvest index (%)		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	7,026	7,221	7,123	7,936	8,153	8,045	46.95	46.96.	46.96
I_2	6,925	7,150	7,037	7,844	8,056	7,956	46.88	47.01	46.95
I_3	6,780	6,988	6,884	7,333	7,545	7,439	48.03	48.08	48.06
SEm±	54.0	60.4	55.2	52.8	52.1	52.4	0.03	0.08	0.03
CD (P=0.05)	150	168	153	147	145	146	NS	NS	NS
Nitrogen (N)									
N_1, 120 kg/ha	6,828	7,034	6,931	7,605	7,817	7,711	47.32	47.37	47.34
N_2, 160 kg/ha	6,924	7,131	7,028	7,710	7,921	7,816	47.32	47.38	47.35
N_3, 200 kg/ha	6,979	7,193	7,086	7,798	8,016	7,907	47.23	47.30	47.27
SEm±	37.2	44.5	39.0	41.0	41.1	41.0	0.04	0.10	0.07
CD (P=0.05)	81	97	85	89	89	89	NS	NS	NS
Varieties (V)									
V_1, 'KNM 118'	6,950	7,168	7,059	7,742	7,952	7,847	47.31	47.41	47.36
V_2, 'JGL 18047'	6,871	7,071	6,971	7,667	7,884	7,776	47.27	47.29	46.28
SEm±	47.2	48.9	47.1	44.7	43.7	44.2	0.07	0.09	0.07
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

with the application of 160 kg N/ha (N_2). These results are in conformity with the findings of Babu *et al*., (2013). The grain yield of rice was not influenced significantly by varieties; however, higher grain yield was recorded with the variety 'KNM 118' (7,059 kg/ha) which was 1.26% higher than the variety 'JGL 18047' (6,971 kg/ha).

Irrigation maintained at the recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) resulted in significantly higher straw yield (8,045 kg/ha) and it was at par with AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2). The increase in straw yield in recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) and AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) might be owing to favourable vegetative growth and development.

The maximum straw yield was registered with the application of 200 kg N/ha (N_3) (7907 kg/ha), being was at par with the application of 160 kg N/ha (N_2) (7,816 kg/ha).

Nutrient uptake at harvesting

Nitrogen uptake: Among the irrigation regimes, nitrogen uptake did not differ significantly at tillering (Table 5). However, irrigation maintained at the recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) (62.34 kg/ha and 105.34 kg/ha) and AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) were statistically at par with each other at panicle-initiation and flowering stage. This could be because of increased availability and efficient absorption of nutrients from the soil and transport of nutrients from roots to shoots and grains. Similar results were observed by Rahaman and Sinha (2013).

Nitrogen uptake was significantly higher with the application of 200 kg N/ha (N_3) (20.50, 60.91, 104.97 and 128.29 kg/ha at tillering, panicle initiation, flowering and at harvesting) and was superior to application of 160 kg N/ha (N_2) and 120 kg N/ha (N_1) (Table 6). Similar trend of nitrogen uptake was found with application of 200 kg N/ha (N_3) in grain (87.22 kg/ha) and in straw (41.57 kg/ha). This might be owing to nitrogen supply matches with the crop demand that led to higher uptake of nitrogen. These results are in tune with the findings of Duttarganvi *et al*., (2011).

Phosphorus uptake: Irrigation maintained at recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) resulted in significantly higher phosphorus uptake during both the years, i.e. 24.65 in grain, 17.96 in straw and 42.62 kg/ha of total P uptake on, than AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) and AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe (I_3) (Table 7). These results are in agree-

Table 5. Nitrogen uptake (kg/ha) at different growth stages of rice as influenced by alternate wetting and drying irrigation, nitrogen levels and varieties during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Tillering			Panicle initiation			Flowering		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	19.14	20.26	19.70	62.20	62.48	62.34	104.32	106.29	105.24
I_2	18.54	20.18	19.36	57.20	58.19	57.69	100.71	102.62	101.67
I_3	18.18	19.82	19.00	55.09	55.94	55.51	96.78	98.69	97.73
SEm±	0.27	0.22	0.23	1.84	1.55	1.69	1.31	1.35	1.29
CD (P=0.05)	NS	NS	NS	5.12	4.32	4.69	3.65	3.76	3.59
Nitrogen (N)									
N_1, 120 kg/ha	17.81	19.18	18.50	55.43	56.26	55.85	97.71	99.28	98.49
N_2, 160 kg/ha	18.29	19.84	19.06	58.53	59.05	58.79	100.14	102.34	101.24
N_3, 200 kg/ha	19.76	21.24	20.50	60.53	61.28	60.91	103.96	105.98	104.97
SEm±	0.42	0.27	0.32	0.88	0.94	0.90	0.77	0.72	0.73
CD (P=0.05)	0.92	0.69	0.70	1.93	2.04	1.96	1.69	1.58	1.59
Varieties (V)									
V_1, 'KNM 118'	18.63	20.13	19.38	58.29	58.90	58.59	101.21	103.13	102.17
V_2, 'JGL 18047'	18.61	20.05	19.33	58.04	58.83	58.44	100.00	101.94	100.97
SEm±	0.28	0.28	0.26	0.43	0.42	0.40	0.67	0.69	0.65
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

Table 6. Effect of alternate wetting and drying irrigation, nitrogen levels and varieties on nitrogen uptake (kg/ha) at harvesting during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Nitrogen uptake at harvesting (kg/ha)								
	Grain			Straw			Total		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	86.93	88.65	87.79	40.96	41.95	41.45	127.90	130.60	129.25
I_2	82.65	86.86	84.76	40.36	41.77	41.06	123.01	128.64	125.83
I_3	77.50	83.28	80.39	35.46	36.65	36.05	115.96	119.93	117.95
SEm±	1.69	0.74	1.19	0.24	0.41	0.29	1.78	1.09	1.42
CD (P=0.05)	4.71	2.07	3.31	0.68	1.15	0.82	4.95	3.03	3.94
Nitrogen (N)									
N_1, 120 kg/ha	81.04	84.70	82.87	36.58	37.78	37.18	117.62	122.48	120.05
N_2, 160 kg/ha	82.56	86.13	84.34	39.31	40.33	39.82	122.88	126.47	124.67
N_3, 200 kg/ha	86.48	87.96	87.22	40.89	42.25	41.57	126.37	130.21	128.29
SEm±	1.44	0.70	1.45	0.31	0.29	0.27	1.55	0.88	1.06
CD (P=0.05)	3.14	1.53	2.31	0.69	0.63	0.59	3.39	1.93	2.32
Varieties (V)									
V_1, 'KNM 118'	84.36	86.75	85.56	38.92	40.03	39.48	123.29	126.78	125.04
V_2, 'JGL 18047'	82.35	85.78	84.07	38.93	40.21	39.57	121.29	126.00	123.64
SEm±	1.24	0.64	1.26	0.38	0.28	0.32	1.35	0.77	0.98
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

ment with the findings of Ramakrishna *et al*., (2007) and Rahaman and Sinha (2013).

Application of 200 kg N/ha (N_3) was superior (24.25 kg/ha) in phosphorus uptake of grain over application of 120 kg N/ha (N_1) but was on a par with the application of 160 kg N/ha (N_2). Phosphorus uptake in straw was significantly higher with application of 200 kg N/ha (N_3), i.e. 17.49 kg/ha and total uptake of 41.75 kg/ha, than the application of 160 kg N/ha (N_2).

Potassium uptake: Irrigation maintained at recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) resulted in significantly higher potassium uptake during both the years of study (34.35, 104.36 and 138.71 kg/ha in grain, straw and total uptake respectively) over AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) (Table 8). Application of 200 kg N/ha (N_3) was superior in potassium uptake of grain, straw and total uptake (33.98, 101.33 and 135.31 kg/ha) over application of 120 kg N/ha (N_1).

Economics

Irrigation maintained at the recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) resulted higher cost of cultivation (₹42,893/ha), followed by AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) (₹41,823/ha) and AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe (I_3) recorded lower cost of cultivation (₹40,968/ha) (Table 9). This was due to higher number of irrigations applied to recommended submergence of 2–5 cm water level as per crop-growth stage (I_1). Among the nitrogen levels, an application of 200 kg N/ha (N_3) exhibited higher cost of cultivation (₹42,379/ha), followed by 160 kg N/ha (N_2) (₹41,895/ha) and the lowest cost of cultivation was with application of 120 kg N/ha (N_1) (₹41,411/ha). The cost of cultivation was equal in all the plots of both varieties during both the years of study.

Among the irrigation regimes, recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) fetched significantly higher net returns (₹57,202/ha) which were comparable with AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) but both the treatments were significantly superior to AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe (I_3) (Table 9). Higher net returns were attributed to higher grain and straw yields in recommended submergence of 2–5 cm water level as per crop-growth stage (I_1) and AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) treatments.

Among the nitrogen levels, an application of 200 kg N/ha (N_3) resulted in significantly higher net returns

Table 7. Phosphorus uptake (kg/ha) at harvesting of rice as influenced by alternate wetting and drying irrigation, nitrogen levels and varieties during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Phosphorus uptake at harvesting (kg/ha)								
	Grain			Straw			Total		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	24.31	24.99	24.65	17.72	18.21	17.96	42.04	43.20	42.62
I_2	23.46	24.22	23.84	17.08	17.54	17.31	40.55	41.77	41.16
I_3	22.37	23.06	22.72	15.44	15.89	15.66	37.82	38.95	38.39
SEm±	0.20	0.21	0.20	0.19	0.20	0.19	0.36	0.36	0.36
CD (P=0.05)	0.56	0.60	0.57	0.54	0.55	0.55	1.00	1.01	0.99
Nitrogen (N)									
N_1, 120 kg/ha	22.76	23.45	23.11	16.24	16.69	16.46	39.01	40.15	39.58
N_2, 160 kg/ha	23.50	24.21	23.86	16.75	17.21	16.98	40.26	41.42	40.84
N_3, 200 kg/ha	23.88	24.62	24.25	17.25	17.73	17.49	41.14	42.36	41.75
SEm±	0.20	0.22	0.20	0.11	0.12	0.11	0.27	0.28	0.27
CD (P=0.05)	0.44	0.49	0.45	0.25	0.26	0.26	0.60	0.63	0.60
Varieties (V)									
V_1, 'KNM 118'	23.50	24.24	23.87	16.81	17.27	17.04	40.32	41.52	40.92
V_2, 'JGL 18047'	23.26	23.94	23.60	16.68	17.15	16.92	39.95	41.10	40.53
SEm±	0.17	0.18	0.17	0.14	0.14	0.14	0.28	0.28	0.28
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

Table 8. Effect of alternate wetting and drying irrigation, nitrogen levels and varieties on potassium uptake (kg/ha) at harvesting of rice during the winter season (2016–17, 2017–18 and pooled means)

Treatment	Potassium uptake at harvesting (kg/ha)								
	Grain			Straw			Total		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	33.88	34.82	34.35	102.95	105.76	104.36	136.83	140.59	138.71
I_2	32.89	33.86	33.42	99.75	102.44	101.10	132.64	136.41	134.52
I_3	31.52	32.49	32.01	92.02	94.68	93.35	123.55	127.18	125.37
SEm±	0.29	0.34	0.31	0.57	0.57	0.57	0.85	0.86	0.86
CD (P=0.05)	0.82	0.95	0.86	1.60	1.59	1.59	2.38	2.40	2.38
Nitrogen (N)									
N_1, 120 kg/ha	31.98	32.94	32.46	96.46	99.15	97.80	128.44	132.10	130.27
N_2, 160 kg/ha	32.85	33.84	33.34	98.33	101.02	99.67	131.19	134.86	133.02
N_3, 200 kg/ha	33.46	34.49	33.98	99.93	102.73	101.33	133.40	137.22	135.31
SEm±	0.22	0.26	0.23	0.51	0.52	0.52	0.68	0.70	0.69
CD (P=0.05)	0.49	0.57	0.52	1.12	1.14	1.13	1.49	1.54	1.51
Varieties (V)									
V_1, 'KNM 118'	32.84	33.88	33.36	98.77	101.45	100.11	131.62	135.34	133.48
V_2, 'JGL 18047'	32.68	33.63	33.16	97.71	100.47	99.09	130.39	134.11	132.25
SEm±	0.24	0.25	0.24	0.56	0.55	0.55	0.77	0.74	0.75
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Interactions (I×N, I×V, N×V, I×N×V)	NS	NS	NS	NS	NS	NS	NS	NS	NS

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

Table 9. Cost of cultivation, net returns (₹/ha) and benefit: cost ratio of rice as affected by alternate wetting and drying irrigation, nitrogen levels and varieties during winter season (2016–17, 2017–18 and pooled means)

Treatment	Cost of cultivation (× 10^3 ₹/ha)			Net returns (× 10^3 ₹/ha)			Benefit: cost		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Irrigation regimes (I)									
I_1	43.1	42.6	42.8	56.2	58.7	57.2	1.30	1.36	1.32
I_2	41.9	41.6	41.8	55.2	58.7	56.9	1.31	1.40	1.36
I_3	41.1	40.7	40.9	53.5	55.4	54.5	1.30	1.36	1.33
SEm±	–	–	–	712	248	456	0.02	0.006	0.01
CD (P=0.05)	–	–	–	1.9	0.6	1.2	NS	0.01	NS
Nitrogen (N)									
N_1, 120 kg/ha	41.6	41.2	41.4	53.9	56.4	55.2	1.30	1.37	1.33
N_2, 160 kg/ha	42.0	41.6	41.8	54.9	57.4	56.1	1.30	1.37	1.34
N_3, 200 kg/ha	42.5	42.1	42.3	56.1	58.3	57.2	1.30	1.38	1.34
SEm±	–	–	–	552	632	570	0.01	0.01	0.01
CD (P=0.05)	–	–	–	1.2	1.3	1.2	NS	NS	NS
Varieties (V)									
V_1, 'KNM 118'	42.0	41.6	41.8	55.5	57.4	56.5	1.31	1.37	1.34
V_2, 'JGL 18047'	42.0	41.6	41.8	54.4	57.4	55.9	1.28	1.37	1.33
SEm±	–	–	–	632	384	483	–	–	–
CD (P=0.05)	–	–	–	NS	NS	NS	–	–	–
Interactions (I×N, I×V, N×V, I×N×V)	–	–	–	NS	NS	NS	–	–	–

I_1, Recommended submergence of 2–5 cm water level as per crop-growth stage; I_2, alternate wetting and drying (AWD) irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe; I_3, AWD irrigation of 5 cm when water level falls below 5 cm from soil surface in perforated pipe

(₹57,247/ha), being at par with application of 160 kg N/ha (N_2).

Irrigation regimes did not influence the benefit: cost (B:C) ratio of rice. However, AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) recorded significantly higher B : C ratio (1.40). This might be owing to higher grain and straw yields with less cost of cultivation as compared to the recommended submergence of 2–5 cm water level as per crop-growth stage (I_1). Nitrogen levels and varieties did not influence the B : C ratio of rice (Table 9).

There was no significant difference in terms of growth, yield attributes, yield, nutrient uptake and economics between rice varieties 'KNM 118' and 'JGL 18047' with continuous submergence and alternate wetting and drying irrigation under different nitrogen levels during the winter (*rabi*) season.

It can be concluded that growth, yield, nutrient uptake, gross returns, net returns of rice varieties 'KNM 118' and 'JGL 18047' under AWD irrigation of 5 cm when water level falls below 3 cm from soil surface in perforated pipe (I_2) was on a par with the recommended submergence of 2-5 cm water level as per crop-growth stage and application of 160 kg N/ha has shown comparable performance with 200 kg N/ha (N_3) growth, yield, nutrient uptake and net returns of rice during the winter (*rabi*) season.

REFERENCES

Azarpour, E., Tarighi, F., Moradi, M. and Bozorgi, H.R. 2011. Evaluation effect of different nitrogen fertilizer rates under irrigation management in rice farming. *World Applied Science Journal* **13**(5): 1,248–1,252.

Babu, P.V.R, Rao, Ch.P., Subbaiah, G. and Rani, Y.A. 2013. Effect of different levels of nitrogen and phosphorus on growth and yield of *kharif* rice (*Oryza sativa* L.). *The Andhra Agricultural Journal* **60**(3): 528–534.

Buresh, R.J. and Haefele, S.M. 2010. Changes in paddy soils under transition to water saving and diversified cropping systems. (In) Paper presented at World Congress of Soil Science, Brisbane, Australia, 1–6 August 2010.

Duttarganvi, S., Channabasavanna, A.S., Halepyati, A.S., Nagalikar, V.P., Satyanarayan Rao and Vasudevan, S.N. 2011. Economic adoptability of leaf colour chart and chlorophyll meter in nitrogen management in low land rice (*Oryza sativa* L.). *Karnataka Journal of Agricultural Sciences* **24**(4): 531–532.

Ghanshyam, P. 2016. Optimization of nitrogen scheduling for higher productivity of machine transplanted rice (*Oryza sativa* L.) in Southern Telangana Zone of Telangana. Ph.D. Thesis. Professor Jayashankar Telangana State Agricultural University, Hyderabad.

Jayanthi, T., Gali, S.K., Chimmad, V.P. and Angadi, V.V. 2007. Leaf colour chart based N management on yield, harvest index and partial factor productivity of rainfed rice. *Karnataka Journal of Agricultural Sciences* **20**(2): 405–406.

Meena, S., Singh, S and Shivay, Y.S. 2003. Response of hybrid rice (*Oryza sativa*) to nitrogen and potassium application in sandy clay soils. *Indian Journal of Agronomy* **44**(4): 717–721.

Rahaman, S and Sinha, A.C. 2013. Effect of water regimes and organic sources of nutrients for higher productivity and nitrogen use efficiency of summer rice (*Oryza sativa*). *African Journal of Agricultural Research* **8**(48): 6,189–6,195.

Ramakrishna, Y., Singh, S and Parihar, S.S. 2007. Influence of irrigation regime and nitrogen management on productivity, nitrogen uptake and water use by rice (*Oryza sativa*). *Indian Journal of Agronomy* **52**(2): 102–106.

Rao, A.N., Johnson, D.E., Sivaprasad, B., Ladha, J.K and Mortimer, A.M. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153–255.

Singh, F., Kang, J.S., Singh, A and Singh, T. 2015. Nutrient uptake, nutrient availability and quality parameters of mechanically transplanted rice (*Oryza sativa* L.) under split doses of nitrogen. *Agricultural Science Digest* **35**(2): 95–100.