Original Research Article

Optimizing Growth and Yield in Aerobic Rice through IoT-based Drip Irrigation and Fertigation

ABSTRACT

Aim: A field experiment was conducted to study the effect of different IoT based drip irrigation and fertigation management practices on growth and yield of aerobic rice.
Study design: The experiment was laid out in a strip plot design with 4 main plots (Horizontal) and 3 sub-plots (Vertical) that are allocated randomly and replicated thrice.
Place and Duration of Study:*kharif* and *rabi* seasons of 2022-23 & 2023-24 at ICAR-Indian Institute of Rice Research, Hyderabad.
Methodology: The horizontal plot treatments were Nitrogen management practices (4) i.e., Control (N_1), 100 % RDN (100% inorganic) (N_2), 100 % RDN (50% inorganic & 50% organic) (N_3) and 125 % RDN (100 % inorganic) (N_4). Vertical plots treatments were Irrigation management practices (3) which includeSaturation (I_1), 10 % DASM (I_2) and 20 % DASM (I_3). Organic nutrient sources were given as soil application and the inorganic sources were applied through fertigation. Sensor based (IoT) irrigation scheduling was done.
Results: Nitrogen application of 125% RDN with 100% inorganic consistently resulted in higher growth parameters (plant height (110.4 cm and 93.9 cm), number of tillers m^{-2}(392.2 and 291.8) and plant dry weight (11814.8 kg $ha^{-1}$and 9557.0 kg ha^{-1}) during *kharif*&*rabi* respectively) followed by 100% RDN (100% inorganic) and 100% RDN (50% inorganic & 50% organic) in pooled data. Saturation irrigation resulted in taller plants with greater growth parameters(plant height (109.8 cm and 91.0 cm), number of tillers m^{-2}(412.3 and 283.6) and plant dry weight (10916.0 kg $ha^{-1}$and 9463.4 kg ha^{-1}) during *kharif*&*rabi* respectively) compared to deficit irrigation treatments. Treatment of 125% RDN with 100% inorganic resulted in the higher yield attributes (no. of panicles m^{-2}(154.3 and 141.1), no. of filled grains $panicle^{-1}$ (142.3 and 124.0), panicle weight (3.1 g and 3.3 g) during *kharif*&*rabi* respectively) and yield (4790.2 kg $ha^{-1}$and 4583.8 kg ha^{-1}) which was statistically similar with 100% RDN (100% inorganic) and 100% RDN (50% inorganic & 50% organic). Saturation expressed higher yield attributes (no. of panicles m^{-2}(149.5 and 139.2), no. of filled grains $panicle^{-1}$ (135.0 and 121.6), panicle weight (3.0 g and 3.2 g) during *kharif*&*rabi* respectively) and yield (4554.0 kg $ha^{-1}$and 4425.5 kg ha^{-1}) which was on par with 10% DASM.The interaction was found to be non-significant.
Conclusion: Nitrogen application of 125% RDN and 100% RDN through fertigation were found to have statistically similar growth, yield parameters and yield. IoT based irrigation at 10% DASM was found to be on par with saturation treatment among all the growth, yield parameters and yield ofaerobic rice.

Keywords:Aerobic rice, IoT, sensor, nitrogen, drip irrigation

INTRODUCTION

Agriculture is the cornerstone of human civilization, providing food, fiber, and other essential resources for a growing global population. In the face of mounting challenges such as climate change, resource scarcity, and the need for increased food production, it has become imperative to harness innovative technologies to enhance the efficiency and sustainability of agricultural practices [1],[2]. One such innovative approach is the utilization of Internet of Things (IoT) technology in precision agriculture [3].
Rice is a staple crop that sustains millions of people worldwide, playing a crucial role in global food security [4]. Traditionally, rice cultivation has been associated with flooded fields, known as paddies, which are water-intensive and often environmentally unsustainable [5]. In recent years, there has been a growing shift towards more sustainable and water-efficient methods of rice cultivation, with aerobic rice emerging as a promising alternative. Aerobic rice is grown under

non-flooded conditions, conserving water resources while offering the potential for increased yield and improved resource management. One of the key challenges in cultivating aerobic rice lies in optimizing water and nutrient delivery to ensure robust growth. This is where modern technology, particularly the Internet of Things (IoT), comes into play. IoT-based systems offer the potential to monitor and manage various agricultural processes remotely and in real-time, making them highly suitable for precision agriculture applications.

This research paper focuses on the application of IoT-based drip irrigation and fertigation in the cultivation of aerobic rice, a water-efficient and environmentally-friendly method of rice production [6]. Aerobic rice, also known as upland rice, has gained popularity due to its reduced water requirements, increased resilience to drought, and improved resource-use efficiency compared to traditional flooded rice cultivation [7]. The integration of IoT technology into aerobic rice farming promises to further revolutionize this sustainable agricultural practice. IoT-based drip irrigation and fertigation offer the potential to optimize the use of water and nutrients, tailoring their application to the specific needs of the rice crop in real-time [8]. By continuously monitoring and adjusting irrigation and fertilization parameters, farmers can maximize yields while conserving water and minimizing environmental impacts. Furthermore, the IoT technology allows for remote monitoring and control, enabling farmers to make informed decisions and respond promptly to changing environmental conditions.

This research aims to investigate the effects of IoT-based drip irrigation and fertigation on the growth and yield of aerobic rice by examining key growth indicators, such as plant height, no. of tillers m^{-2}, plant dry weight (kg); yield attributes such as no. of panicles m^{-2}, no. of filled grains $panicle^{-1}$, panicle weight, test weight and yield.

4. MATERIAL AND METHODS

A field experiment entitled "*Optimizing Growth and Yield in Aerobic Rice through IoT-based Drip Irrigation and Fertigation*" was conducted during *kharif&rabi* 2022-2023 and 2023-2024 at ICAR-Indian Institute of Rice Research, Hyderabad situated at an altitude of 542.3 m above mean sea level and located at 17.19^{o}N latitude and 78.23^{o}E longitude. It represents the Southern Telangana agro-climatic zone of Telangana. According to Troll's climatic classification, it falls under semi-arid tropics (SAT). The soil type of the experimental field was sandy clay loam texture with alkaline pH, low in organic carbon and available nitrogen, medium in available phosphorus and higher in available potassium levels. Drought tolerant rice variety DRR Dhan 42 was grown during both the years. The experiment was laid out in a strip plot design with 4 horizontal and 3 vertical plots that are allocated randomly and replicated thrice. Spacing of the crop is 20 cm × 10 cm. Number of hills m^{-2} is 40. The main (Horizontal) plot treatments were Nitrogen management practices (4) which include Control (no nitrogen) (N_1), 100 % RDN (100% inorganic) (N_2), 100 % RDN (50% inorganic & 50% organic) (N_3) and 125 % RDN (100 % inorganic) (N_4). Sub (Vertical) plots treatments were Irrigation management practices (3) which includeSaturation (I_1), 10 % DASM (Depletion of Available Soil Moisture) (I_2) and 20 % DASM (I_3).

The irrigation source is a bore well from which the water is diverted to the plots through drip irrigation. Each plot comprised of five beds of 1 metre with spacing of 20 cm. Four crop rows per each bed were sown with a row spacing of 20 cm. Each lateral was placed in the centre of bed thus one lateral supplies irrigation to four crop rows. It was estimated that an emitter can supply water in a ring of 90-100 cm diameter. Thus, spacing of 1 metre lateral and 50 cm dripper was taken for drip irrigation system.The regular common irrigation practice was followed upto 20 Days after sowing (DAS) for proper stand establishment and weed control in experimental plots. After 20 DAS, sensor-based drip irrigation scheduling was done as per the treatment. To avoid the seepage losses, buffer channels were prepared in between the experimental plots. Recommended dose of nitrogen (RDN) in aerobic rice is 120 kg ha^{-1}. Nitrogen was supplied as per the treatment details. It was applied through fertigation starting from 20 DAS up to 90 DAS using urea (water soluble fertilizer) at weekly interval. Farm yard manure was given as basal application for organic nutrient source in the required treatment. The recommended dose of phosphorus @ 60 kg P_2O_5 kg ha^{-1} as single super phosphate (SSP) and potassium @ 40 K_2O kg ha^{-1} as muriate of potash (MOP) were applied to all the treatments uniformly as basal.

Growth parameterswere recorded at harvest. Plant height was measured from the basal node of the plant to the tip of the topmost leaf at harvest and mean height was presented as cm. In each treatment, one m² area was demarcated in the net plot with small pegs. The above ground portion of the plant was dried in hot air oven at 65°C till the constant weight was obtained and were weighed separately, thenconverted to kg ha^{-1}. The productive tillers were counted and mean of tillers were expressed as number of panicles m^{-2}. Weight of sampled panicles was recorded and expressed in g $panicle^{-1}$.Filled number of grains $panicle^{-1}$ was determined by counting the grains in panicles of randomly selected plants and mean was calculated.Thousand grains were counted and the weight was recorded as test weight in grams (g). Plants in the net plot area were harvested separately in each plot threshed and grains were separated, dried under sun and the grain yield per plot was recorded after cleaning. After threshing the grain, the remaining straw was dried under sun and the yield per hectare was computed..Harvest index (%) is the proportion of total biological yield represented by grain yield as suggested by Donald and Humblin [9].The data obtained on the different parameters were analyzed statistically by the method of analysis of variance as per the procedure outlined for strip plot design given by Gomez and Gomez [10]. Statistical significance was tested by F value at 0.05 level of probability and critical difference was worked out where ever the effects were significant.

3. RESULTS AND DISCUSSION

3.1 Plant height

During the *kharif* season of aerobic rice at harvest among the pooled means, the highest plant height was observed in the treatment N_4 (125% recommended dose of nitrogen (RDN) with 100% inorganic fertilizer) (110.4 cm), which was on par with N_2 (100% RDN with 100% inorganic fertilizer) (107.6 cm) and N_3 (100% RDN with 50% inorganic and 50% organic fertilizer) (103.1 cm), while the control treatment (N_1) exhibited the lowest plant height (97.3 cm). The treatment N_4 (125% recommended dose of nitrogen (RDN) with 100% inorganic fertilizer) (93.9 cm) expressed the tallest plants in *rabi* season at harvest which was statistically comparable with N_2 (100% RDN with 100% inorganic fertilizer) (89.4 cm) followed by N_3 (100% RDN with 50% inorganic and 50% organic fertilizer) (86.9 cm). The shortest plants were observed in control with no nitrogen (78.0 cm) (Table 1). The increase in plant height has been associated with the timely delivery of nutrients in accordance with crop requirements. It has been demonstrated that doing this increases the crop's photosynthetic area and, as a result, photosynthate uptake. These results are supported by Vanitha and Mohandas [11]. If fertigation was carried out more regularly to satisfy nutritional demands and supply the required amount of nutrients during all growth stages without suffering moisture stress, plant height may have increased. Lower plant height was the outcome of inadequate or delayed delivery of irrigation water and essential plant nutrients in surface irrigation. Sampathkumar and Pandian [12] and Binder *et al*. [13] have reported similar outcomes.

Regarding irrigation management in pooled data at harvest, saturation (I_1) consistently resulted in taller plants (109.8 cm and 91.0 cm respectively during *kharif* and *rabi* seasons) compared to 10% DASM (I_2) (105.5 cm and 87.5 cm *viz*. during *kharif* and *rabi*) and 20% DASM (I_3) (98.6 cm and 82.6 cm during *kharif* and *rabi* seasons correspondingly) (Table 1). Constant moisture availability near the crop root zone may contribute to enhanced plant height at higher irrigation scheduling levels. This could lead to increased nutrient uptake, cell division, and elongation. The results were in agreement with the research conducted by Pushpa *et al*. [14], Govindan and Grace [15], and Karthika and Ramanathan [16]. The application of water-soluble fertilizers through fertigation not only maintained adequate water availability but also boosted nutrient uptake and created a consistent supply of nutrients, leading to superior growth attributes. Similar findings have been reported by Veeraputhiran *et al*. [17], Vijaykumar [18] and Kombali *et al.*[19]. Drip fertigation, which applies water and nutrients at certain times to match the crop's need for each at distinct stages, results in taller plants. This was attributed to the constant moisture availability near the root zone, promoting nutrient uptake and cell elongation. Additionally, the application of water-soluble fertilizers through fertigation contributed to improved growth qualities and increased plant height. This aligns with previous research highlighting the benefits of drip fertigation in matching water and fertilizer supply with crop needs.

Overall, there was no significant interaction between nitrogen and irrigation management practices regarding plant height throughout the *kharif* and *rabi* aerobic rice at harvest.

3.2 Number of tillers per m^2

Regarding nitrogen management among pooled means, at harvest, the treatment N_4 - 125% recommended dose of nitrogen (RDN) showed the highest tiller count (392.2 And 291.8 during *kharif* and *rabi* respectively), statistically comparable to N_2 - 100% RDN (100 % inorganic) (377.9 and 281.4 *viz*. during *kharif* and *rabi*) and N_3 - 100% RDN (50% inorganic & 50% organic) (370.4 and 276.3 correspondingly in *kharif* and *rabi*), while N_1 (control) had the lowest tiller count (307.6 and 190.9 in *kharif* and *rabi* respectively).Concerning irrigation management, the treatment I_1-Saturation showed significantly higher tiller count (412.3 and 283.6), comparable to I_2-10% DASM (350.3 and 256.4), while I_3-20% DASM (323.4 and 240.3) exhibited the lowest count during *kharif* and *rabi* season correspondingly in pooled data. There was no significant difference observed in the interaction effect between irrigation and nitrogen management on tiller count at harvest (Table 1). These results were in conformity with Veeraputhiran *et al*. [17], Vijaykumar [18] and Kombali *et al.*[19].

3.3 Dry matter production (kg ha^{-1})

At harvest among pooled means at harvest, the highest plant dry matter productionwas recorded in N_4-125% RDN (100% inorganic) (11814.8 kg ha^{-1} and 9557.0 kg ha^{-1}), which was comparable with N_2-100% RDN (100% inorganic) (10147.7 kg ha^{-1} and 9209.8 kg ha^{-1}) and N_3 - 100% RDN (50% inorganic & 50% organic) (9476.9 kg ha^{-1} and 8988.7 kg ha^{-1}), with both treatments significantly higher than the control (N_1) (7645.5 kg ha^{-1} and 7532.2 kg ha^{-1}), during both *kharif* and *rabi* seasons respectively (Table 1). Increased nitrogen absorption and improved nutrient distribution in the soil resulted from water soluble fertilizer applied at greater concentrations. According to Jena and Aladakatti [20], this may have led to increased nutrient intake and subsequent growth, which in turn produced more dry matter.

Similarly, irrigation management practices influenced plant dry weight significantly. In *kharif* and *rabi* seasons in pooled data at harvest, saturation irrigation (I_1) (10916.0 kg ha^{-1} and 9463.4 kg ha^{-1}) resulted in the highest plant dry weight, followed by 10% DASM (I_2) (10052.4 kg ha^{-1} and 8726.2 kg ha^{-1}), and then 20% DASM (I_3) (8345.3 kg ha^{-1} and 8276.1 kg ha^{-1}) (Table 1). Higher growth parameters attributed to the increased plant dry weight in the respective treatments. Because of frequent fertigation and application of water-soluble fertilizers, which promote the uptake of moisture and nutrients, these treatments may have produced more tillers and leaves, which may have contributed to the increased buildup of dry matter. Rekha *et al*. [21] and Vijaykumar [18] also found similar outcomes.

However, there was no significant interaction between nitrogen and irrigation treatments on plant dry weight at any growth stage.

3.4 Number of Panicles m^{-2}

Among nitrogen management practices during *kharif* and *rabi* in pooled data, N_4 (125% RDN - 100% inorganic) (154.3 and 141.1) showed the highest number of panicles, which was statistically similar to N_2 (100% RDN - 100% inorganic) (153.9 and 139.1) and N_3 (100% RDN - 50% inorganic & 50% organic) (152.4 and 137.5), while N_1 (control) exhibited the lowest number of panicles (132.6 and 126.7) (Table 2). Among irrigation management practices, there was no significant difference observed with respect to number of panicles in both *kharif* and *rabi* seasons. Interaction effects between nitrogen and irrigation treatments were not significant, indicating their independent effects on the number of panicles. Favourable moisture conditions at the panicle initiation stage might have contributed to a higher number of panicles by preserving appropriate cell integrity, division, and elongation as well as enhancing nutrient uptake and eventually increasing sink size. [22]

Table 1. Growth parameters at harvest of aerobic rice as influenced by Nitrogen and Irrigation management practices

Treatments	Growth parameters					
Main plots: Nitrogen management practices (4)	Plant height (cm)		Number of tillers per m^2		Dry matter production (kg ha^{-1})	
	kharif	***Rabi***	***kharif***	***rabi***	***kharif***	***Rabi***
N_1: Control	97.3	78.0	307.6	190.9	7645.5	7532.2
N_2: 100 % RDN (100% inorganic)	107.6	89.4	377.9	281.4	10147.7	9209.8
N_3: 100 % RDN (50% inorganic & 50% organic)	103.1	86.9	370.4	276.3	9476.9	8988.7
N_4: 125 % RDN (100 % inorganic)	110.4	93.9	392.2	291.8	11814.8	9557.0
SEm±	2.6	1.4	12.6	10.7	295.7	168.6
CD at 5%	**9.0**	**4.8**	**43.7**	**36.9**	**1023.4**	**583.4**
CV %	7.5	4.7	10.5	12.3	9.1	5.7
Sub plots: Irrigation management practices (3)						
I_1: Saturation	109.8	91.0	412.3	283.6	10916	9463.4
I_2: 10 % DASM	105.5	87.5	350.3	256.4	10052.4	8726.2
I_3: 20 % DASM	98.6	82.6	323.4	240.3	8345.3	8276.1
SEm±	2.1	0.6	9.2	7.1	406.1	116.5
CD at 5%	**8.2**	**2.3**	**35.9**	**27.8**	**1594.6**	**457.5**
CV %	6.9	2.3	8.8	9.4	14.4	4.6
INTERACTION						
SEm±	-	-	-	-	-	-
CD at 5% N×I	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CD at 5% I×N	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: *The above data is the mean/pooled values of the years 2022-23 and 2023-24*

3.5 Number of Filled Grains Panicle^{-1}

Different nitrogen management practices significantly affected the number of filled grains per panicle. The highest number of filled grains per panicle among the pooled means was observed in N_4-125% RDN (100% inorganic) (142.3 and 124.0 in *kharif* and *rabi* correspondingly), which was statistically similar to N_2-100% RDN (100% inorganic) (135.8 and 123.2 respectively during *kharif* and *rabi*) and N_3-100% RDN (50% inorganic & 50% organic) (135.4 and 120.7 *viz*. in *kharif* and *rabi*). N_1 (control) was found to be the lowest (103.4 and 92.7 during *kharif* and *rabi* respectively). Among irrigation management practices during *kharif* and *rabi* in pooled data, I_1-Saturation resulted in the highest number of filled grains per panicle (135.0 and 121.6), followed by I_2-10% DASM (127.3 and 113.6) and I_3-20% DASM (125.4 and 110.3). Interaction between nitrogen and irrigation treatments was not significant, indicating independence of their effects on filled grain number (Table 2). Similar results were reported by Parthasarathi *et al*. [23], Gireesha [24], and Naik *et al*. [25].

3.6 Panicle Weight (g)

During both *kharif* and *rabi* seasons among the pooled means, N_4 (125% RDN - 100% inorganic) led to the highest panicle weights (3.1 g and 3.3 g), followed by N_2 (100% RDN - 100% inorganic) (3.0 g and 3.2 g) and N_3 (100% RDN - 50% inorganic & 50% organic) (2.9 g and 3.2 g) which were on par with N_4, while N_1 (control) had the lowest panicle weight (2.3 g and 2.6 g) (Table 2). With respect to panicle weight, all irrigation management practices were found to be on par with each other. No significant interaction effect was observed between nitrogen and irrigation treatments. The increased nutrient availability and uptake under drip fertigation may have contributed to improved photosynthesis, leaf growth, and nutrient transfer to reproductive organs, which in turn may have increased yield attributes. Similar results were also noted by Parthasarathi *et al*. [23], Gireesha [24], and Naik *et al*. [25].

3.7 Test Weight (g)

There were no significant effects of either nitrogen or irrigation management practices on test weight. Interaction between nitrogen and irrigation treatments was also not significant. (Table 2)

Table 2. Yield attributes of aerobic rice as influenced by Nitrogen and Irrigation management practices

Treatments	**Yield attributes**							
Main plots: Nitrogen management practices (4)	**Number of panicles m^{-2}**		**No. of filled grains panicle^{-1}**		**Panicle weight (g)**		**Test weight (g)**	
	kharif	***rabi***	***kharif***	***rabi***	***kharif***	***rabi***	***kharif***	***rabi***
N_1: Control	132.6	126.7	103.4	92.7	2.3	2.6	21.6	21.2
N_2: 100 % RDN (100% inorganic)	153.9	139.1	135.8	123.2	3.0	3.2	21.7	21.6
N_3: 100 % RDN (50% inorganic & 50% organic)	152.4	137.5	135.4	120.7	2.9	3.2	21.6	21.5
N_4: 125 % RDN (100 % inorganic)	154.3	141.1	142.3	124.0	3.1	3.3	21.8	22.0
SEm±	2.1	2.7	2.4	2.0	0.1	0.1	-	-
CD at 5%	**7.2**	**9.3**	**8.2**	**6.9**	**0.3**	**0.4**	**NS**	**NS**
CV %	4.2	5.9	5.5	5.2	9.0	11.7	0.8	3.5
Sub plots: Irrigation management practices (3)								
I_1: Saturation	149.5	139.2	135.0	121.6	3.0	3.2	21.8	21.6
I_2: 10 % DASM	148.3	136.5	127.3	113.6	2.9	3.1	21.7	21.6
I_3: 20 % DASM	147.1	132.6	125.4	110.3	2.6	3.0	21.5	21.5
SEm±	-	-	1.8	1.9	-	-	-	-
CD at 5%	**NS**	**NS**	**6.9**	**7.4**	**NS**	**NS**	**NS**	**NS**
CV %	3.0	3.3	4.7	5.7	9.9	6.1	1.1	2.5
INTERACTION								
SEm±	-	-	-	-	-	-	-	-
CD at 5% N×I	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CD at 5% I×N	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: *The above data is the mean/pooled values of the years 2022-23 and 2023-24*

3.8 Grain Yield (kg ha^{-1})

Among the nitrogen management practices in *kharif* and *rabi* aerobic rice, N_4 -125% RDN (100% inorganic) (4790.2 kg ha^{-1} and 4583.8 kg ha^{-1}) resulted in the highest grain yield which was on par with N_2-100% RDN (100% inorganic) (4629.7 kg ha^{-1} and 4477.9 kg ha^{-1}) and N_3-100% RDN (50% inorganic & 50% organic) (4462.7 kg ha^{-1} and 4385.4 kg ha^{-1}) during *kharif* and *rabi* in pooled means. N_1-Control (2952.3 kg ha^{-1} and 3307.6 kg ha^{-1}) led to the least grain yield significantly (Table 3& Fig. 1). Higher yields were seen in the fertigation condition due to increased nutrient availability and solubility in the root zone. Grain filling in aerobic rice requires extra carbohydrates from post-anthesis photosynthesis, according to a study conducted in China by Zhang *et al.* [26]. To achieve a high harvest index and a high percentage of full grains, the fertilizer-N delivery regime needs to promote dry matter production between pre- and post-anthesis.

Significantly higher grain yield among the irrigation management practices was observed in the treatment I_1-Saturation (4554.0 kg ha^{-1} and 4425.5 kg ha^{-1}) which was statistically similar to I_2-10% DASM (4251.5 kg ha^{-1} and 4208.9 kg ha^{-1}) during *kharif* and *rabi* in pooled data. The grain yield was recorded to be lowest in the treatment I_3-20% DASM (3820.7 kg ha^{-1} and 3931.6 kg ha^{-1}) (Table 3& Fig. 1). The lowest grain yield was caused by reduced rates of photosynthate translocations due to either a lower leaf area index or direct inhibition of the translocation system. A larger proportion of sterility in grains was also attributed to increased moisture stress [25][27][14]. It was caused by the root zone having less accessible moisture, and yield characteristics are decreased when moisture stress occurs at critical places. The primary factors limiting grain yield, according to Fukai *et al*. [28], are sink capacity and the grain's capability to absorb assimilates. Similar results were also reported by Kombali *et al*. [29] and Dada *et al.*[30].
There was no significant interaction effect observed between nitrogen and irrigation treatments in any of the analyzed data, indicating that the effects of these two management practices on grain yield are independent of each other.

Table 3. Yield of aerobic rice as influenced by Nitrogen and Irrigation management practices

Treatments	**Yield**					
Main plots: Nitrogen management practices (4)	**Grain yield (kg ha^{-1})**		**Straw yield (kg ha^{-1})**		**Harvest Index (%)**	
	kharif	***rabi***	***kharif***	***rabi***	***kharif***	***Rabi***
N_1: Control	2952.3	3307.6	3524.2	3852.8	45.5	46.2
N_2: 100 % RDN (100% inorganic)	4629.7	4477.9	5237.2	5138.5	46.9	46.6
N_3: 100 % RDN (50% inorganic & 50% organic)	4462.7	4385.4	4961.8	5034.9	47.3	46.5
N_4: 125 % RDN (100 % inorganic)	4790.2	4583.8	5542.5	5279.3	46.4	46.5
SEm±	112.9	125.5	140.9	127.6	-	-
CD at 5%	**390.6**	**434.2**	**487.5**	**441.6**	**NS**	**NS**
CV %	8.05	9.0	8.8	7.9	3.1	1.0
Sub plots: Irrigation management practices (3)						
I_1: Saturation	4554.0	4425.5	5194.1	5059.5	46.7	46.6
I_2: 10 % DASM	4251.5	4208.9	4892.1	4852.1	46.4	46.4
I_3: 20 % DASM	3820.7	3931.6	4363.0	4567.5	46.5	46.3
SEm±	99.98	74.8	148.7	88.1	-	-
CD at 5%	**392.6**	**293.8**	**583.8**	**346.1**	**NS**	**NS**
CV %	8.2	6.2	10.7	6.3	2.9	0.9
INTERACTION						
SEm±	-	-	-	-	-	-
CD at 5% N×I	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
CD at 5% I×N	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Note: *The above data is the mean/pooled values of the years 2022-23 and 2023-24*

3.9 Straw Yield (kg ha^{-1})

Straw yield was significantly influenced by different nitrogen management practices. The highest straw yield was seen in the treatment N_4-125% RDN (100% inorganic) (5542.5 kg ha^{-1} and 5279.3 kg ha^{-1}) during *kharif* and *rabi* in pooled means and was statistically comparable to N_2. There was no significant difference between N_2-100% RDN (100% inorganic) (5237.3 kg ha^{-1} and 5138.5 kg ha^{-1}) and N_3-100% RDN (50% inorganic & 50% organic) (4961.8 kg ha^{-1} and 5034.9 kg ha^{-1}). Straw yield was found to be lowest in N_1-Control (3524.2 kg ha^{-1} and 3852.8 kg ha^{-1}).

Similar to grain yield, I_1-Saturation (5194.1 kg ha^{-1} and 5059.5 kg ha^{-1}) during *kharif* and *rabi* in pooled means recorded the highest straw yield among the irrigation management practices which have no significant difference with I_2-10% DASM (4892.1 kg ha^{-1} and 4852.1 kg ha^{-1}). The treatment I_3-20% DASM led to the lowest straw yield (4363.0 kg ha^{-1} and 4567.5 kg ha^{-1}). (Table 3& Fig. 1)

Higher plant height, more tillers, bigger leaf area, and an overall increase in dry matter production could all lead to a higher straw yield. Naik *et al*. [25] and Kombali [31] offered evidence in favour of these conclusions. Increased photosynthetic activity led to the production of more photosynthates and better growth characteristics, which in turn were associated with a bigger yield of straw and an accumulation of dry matter. Increased leaf area has enhanced crop growth and productivity by enhancing light interception, claim Naik *et al*. [25]. Reduced growth characteristics and a reduction in the total amount of dry matter produced could have been the cause of the lower straw yield, which could be attributed to the somewhat smaller leaf area. Comparable outcomes were reported by Fanish *et al.*[32] and Anusha [33].

The interaction effect between nitrogen and irrigation treatments on straw yield of aerobic rice crop was found to be non-significant in any of the above data during both *kharif* and *rabi* in pooled data.

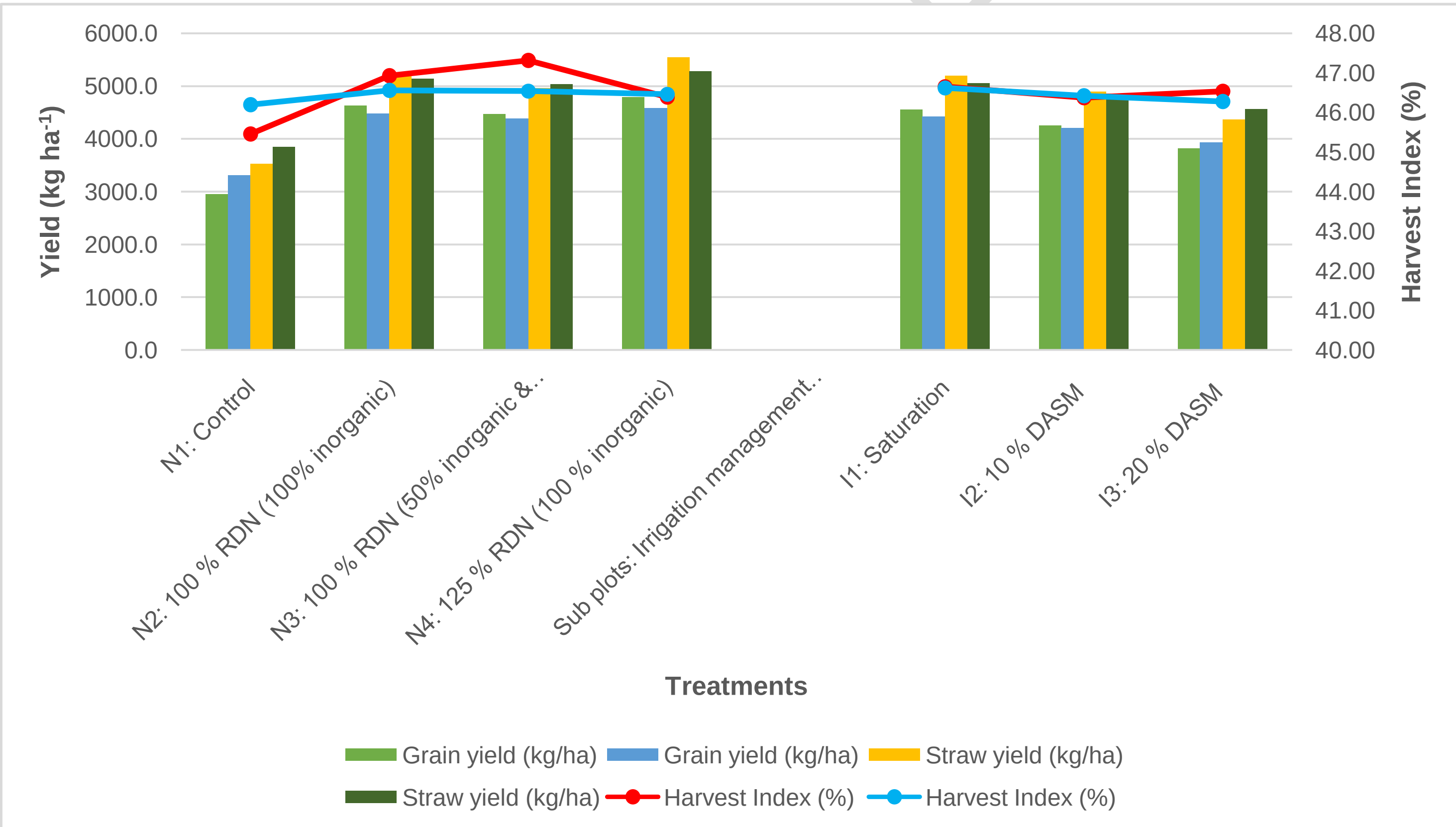

Figure 1. Yield of aerobic rice as influenced by Nitrogen and Irrigation management practices

3.10 Harvest Index (%)

During *kharif* and *rabi* in pooled means among the nitrogen management practices, the harvest index was found to be with no significant difference. Among the pooled means, irrigation management treatments failed to affect the harvest index significantly in *kharif* and *rabi* aerobic rice crops. (Table 3& Fig. 1)

CONCLUSION

Nitrogen application, particularly 125% RDN with 100% inorganic followed by 100% RDN (100% inorganic) and 100% RDN (50% inorganic & 50% organic), consistently resulted in higher growth parameters, while saturation irrigation among the irrigation management treatments consistently led to taller plants with greater growth parameters compared to deficit irrigation treatments. Treatment of 125% RDN with 100% inorganic resulted in the higher yield attributes and yield which was found to be statistically similar with 100% RDN (100% inorganic) and 100% RDN (50% inorganic & 50% organic). Among the irrigation management treatments, Saturation expressed higher yield parameters and yield followed by I_2-10% DASMand I_3-20% DASM. Nitrogen application of 125% RDN and 100% RDN through fertigation were found to have statistically similar growth, yield parameters and yield. IoT based irrigation at 10% DASM was found to be on par with saturation among all the growth, yield parameters and yield of *kharif* aerobic rice.

REFERENCES

1. Lobell DB, Schlenker W and Costa-Roberts J. Climate trends and global crop production since 1980. Science.2011;333(6042): 616-620.
2. Godfray C, Beddington J, Crute I, Haddad L, Lawrence D, Muir J, Pretty J, Robinson S, Thomas S and Toulmin C. Food Security: The Challenge of Feeding 9 Billion People. Science.2010;327:812-8.
3. Zhang N, Wang M and Wang Ning. Precision agriculture - A worldwide overview. Computers and Electronics in Agriculture.2002;36:113-132.
4. Khush GS. What it will take to feed 5.0 billion rice consumers in 2030. Plant Molecular Biology. 2005;59(1):1-6.
5. Bouman B, Peng S, Castañeda AR and Visperas RM. Yield and water use of irrigated tropical aerobic rice systems. Agricultural Water Management.2005;74:87-105.
6. Bouman BA and Tuong TP. Field water management to save water and increase its productivity in irrigated lowland rice. Agricultural Water Management. 2001;49(1): 11-30.
7. Cassman KG, Dobermann A, Walters DT and Yang H. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review of Environment and Resources.2003;315-358.
8. Ray PP. Internet of things for smart agriculture: Technologies, practices and future direction. Journal of Ambient Intelligence and Smart Environments. 2017;9:395-420.
9. Donald CM and Hamblin J. The Biological Yield and Harvest Index of Cereals as Agronomic and Plant Breeding Criteria, Advances in Agronomy, Academic Press, 1976;28: 361-405.
10. Gomez KA and Gomez AA. Statistical Procedures for Agricultural Research. 2nd Edition, John Wiley and Sons, New York, pp 680.1984.
11. Vanitha K and Mohandass S. Effects on yield and yield components and water productivity as influenced by drip fertigation of aerobic rice. International Journal of Agricultural Science.2014;10(1): 390-395.
12. Sampathkumar T and Pandian BJ. Effect of fertigation frequencies and levels on growth and yield of maize. Madras Agricultural Journal.2010;97(7-9): 245-248.
13. Binder DL, Sander DH and Walters DT. Corn response to time of nitrogen application as effected by level of nitrogen deficiency. Agronomy Journal.2000;92: 1228-1236.
14. Pushpa K, Devakumar N, Murthy RK, Nagaraju and Krishnamurthy. Yield and yield attributes of rice genotypes as influenced by methods of irrigation and nitrogen sources. Environment and Ecology.2007;25(4): 774-777.
15. Govindan R and Grace T M. Influence of drip fertigation on growth and yield of rice varieties (*Oryza sativa* L.). Madras Agricultural Journal.2012;99(4-6): 244-247.
16. Karthika N and Ramanathan SP. Effect of drip fertigation on growth, physiological parameters and grain yield of rice grown in Cauvery new delta zone of Tamil Nadu. International Journal of Chemical Studies.2019;7(3): 2758-2761.
17. Veeraputhiran R, Kandasamy OS and Sunder Singh SD. Effect of drip irrigation and fertigation on growth and yield of hybrid cotton. Journal of Agricultural research & Management.2002;1(20): 88-97.

18. Vijaykumar P. Optimization of water and nutrient requirement for yield maximization in hybrid rice under drip fertigation system rice (*Oryza sativa* L.). M.Sc. (Agri.) Thesis, Tamil Nadu Agricultural University, Coimbatore. 2009.
19. Kombali G, Nagaraju, Rekha B, Sheshadri T, Thimmegowda MN and Mallikarjuna G B. Optimization of water and nutrient requirement through drip fertigation in aerobic rice. International Journal of Bio-resource and Stress Management.2016;7(2): 300-304.
20. Jena P and Aladakatti YR. Effect of conventional and water soluble fertilizers through fertigation on growth, physiology and yield of bt cotton. International Journal of Current Microbiology and Applied Sciences.2018;Sp-7: 752-759.
21. Rekha B, Jayadeva HM, Kombali G, Nagaraju, Mallikarjuna GB and Geethakumari A. Growth and yield of aerobic rice grown under drip fertigation. The Ecoscan.2015;9(1&2): 435-437.
22. Singh S, Tripathi R P, Sharma P and Kumar R. Effect of tillage on root growth, crop performance and economics of rice. Indian Journal of Agricultural Sciences.2004. 74(6): 300-304.
23. Parthasarathi T, Vanitha K, Mohandass S, Vered E, Meenakshi V, Selvakumar D, Surendran A and Lazarovitch N. Effect of drip irrigation on growth, physiology, yield and water use of rice. Journal of Agricultural Science.2017;9(1): 154-163.
24. Gireesha G. Crop establishment studies to increase yield in irrigated cotton (cv. MCU 12). M.Sc. (Ag) Thesis. Tamil Nadu Agricultural University, Coimbatore. 2003.
25. Naik DB, Krishna Murthy R and Pushpa K. Yield and yield components of aerobic rice as influenced drip fertigation. International Journal Science and Nature.2015;6(3): 362-365.
26. Zhang L, Lin S, Bouman BAM, Xue C, Wei F, Tao H, Yang X, Wang H, Zhao, D and Dittert K. Response of aerobic rice growth and grain yield of N fertilizer at two contrasting sites near Beijing, China. Field Crops Research.2009;114: 45-53.
27. Guled MB. Investigation on the performance of rice varieties and water requirement of rice based cropping system. Ph.D Thesis, University of Agricultural Sciences, Bangalore. 1993.
28. Fukai S, Li L, Vizmonte PT and Fischer KS. Control of grain yield by sink capacity and assimilate supply in various rice (*Oryza sativa*) cultivars. Expl Agric. 1991;27: 127- 135
29. Kombali G, Nagaraju, Sheshadri T, Thimmegowda MN and Mallikarjuna GB. Effect of water soluble fertilizers on growth and yield of drip irrigated aerobic rice. International Journal of Agriculture Sciences.2017;9(15): 4101-4103.
30. Dada OA, Okpe JA and Togun AO. Water stress at anthesis and storage temperature affected growth and germinability of rice (*Oryza sativa* L.). Journal of Stress Physiology and Biochemistry.2020;16(1): 5-20.
31. Kombali G. Optimization of water and nutrient requirement through drip fertigation in aerobic rice. M.Sc. (Ag.) Thesis. University of Agricultural Sciences, Bangalore. 2013.
32. Fanis SA, Muthukrishnan P and Manoharan S. Effect of drip fertigation in maize (*Zea mays*) based intercropping system. Indian Journal of Agricultural Research.2011;45(3): 233-238.
33. Anusha S, Nagaraju, Mallikarjuna GB and Kombali G. Influence of drip irrigation scheduling on growth and yield of direct seeded aerobic rice (*Oryza sativa* L.). The Ecoscan.2015;9(1&2): 329-332.