Growth and Yield of Rice (*Oryza sativa* L.) as Influenced by Irrigation Methods and Nano Fertilizers

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ABSTRACT

Background: Globally rice is cultivated under lowland condition. Increasing water scarcity and imbalanced fertilizer application affects the productivity of rice. Effective as well as efficient irrigation method and proper nutrient management enhance the growth and yield of rice besides increasing the input use efficiency.

Methods: A field experiment was carried in Agricultural College and Research Institute at Madurai during *Kharif* season 2022. Design executed was split plot with three main and seven sub plots. Irrigation methods was assigned to main plot and nutrient management to sub plot.

Result: The experiment result revealed that adopting alternate wetting and drying irrigation method coupled with combination of 50 percent N and K given as conventional fertilizer + foliar spray of Nano N and K had significant impact on growth attributes, physiological characters and yield beside with limited use of inputs.

Key words: Irrigation, Nano fertilizers, Nutrient, Rice.

INTRODUCTION

Rice is one among the major staple food for a larger part of the world especially in Asia. India is the second largest producer of rice which accounts for 20 per cent of the world's production and it is next to China (Chandana *et al*., 2021). Rice production in India has increased from 80.0 mt in 2005 to 121 mt in 2020 (Economic survey 2005-2020). Among the input resources, water and nutrients are the chief sources which determine the productivity of crops. In recent years, there have been a declining trend in input response or factor productivity with special attention to rice growing tracts. To address the stagnant input response issue besides other factors, alternate or supporting technologies must be developed for pursuing the national food self-sufficiency.

Cultivation of rice area has been declined by several constraints and mainly due to declining availability of water in both quantitative and qualitative terms. To sustain this issue alternate rice cultivation with increased input efficiency techniques has to be adopted. Generally farmers cultivate rice in traditional condition which results in enormous wastage of water with lower water use efficiency compared with other crops and methods of irrigation (Kannan *et al*., 2017). Effective water management is necessary under irrigated rice cultivation as the crop is sensitive to water stress condition. Any attempt to decrease the level of water applied would result in yield penalty and might threaten food security (Duvvada *et al*., 2020). Alternate wetting and drying method is an efficient water saving technique which saves nearly 15 to 30 per cent of water. Another eminent technology is irrigation given with help of field water tube when water level depletes to 10 to 15 cm depth below the soil surface (Santheepan and Ramanathan, 2016).

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Fertilizers play a vital role in increasing the productivity of crops. Among the nutrients, availability of nitrogen determines the crop growth and production. Soil applied N fertilizer is attributed due to several losses and the efficiency of applied N fertilizer is about 30-45 per cent and for K fertilizer it is about 35-40 per cent. Alternative fertilizers or otherwise smart fertilizers pays the way for efficient use of inputs besides enhancing the yield when applied in combination with soil applied fertilizers. In this context, nano fertilizers have a wide potential in improving the crop's yield besides increasing the fertilizer use efficiency due to its environmental safe, ecologically sustainable and economically stable features (Anjuman *et al*., 2017). Thus keeping the above points in consideration, a field trail was carried out to study the impact of irrigation methods and nano fertilizers over the productivity of transplanted rice.

MATERIALS AND METHODS

Study area

The field trail was conducted in Agricultural College and Research Institute at Madurai during *kharif* 2022 which is situated in the southern zone of Tamil Nadu at 9°54′N latitude and 78°54′E longitude with an altitude of 147 m above MSL. It was medium in nitrogen (241.2 kg ha^{-1}) and in phosphorus (16.2 kg ha^{-1}), high in potassium (332.5 kg ha^{-1}) with alkaline pH of 8.1 and EC of 0.47 dsm^{-1}. During the cropping period, total rainfall of 413.9 mm was received in 21 rainy days. The average maximum and minimum temperature recorded were 34.7°C and 24.1°C. With regard to relative humidity, the mean RH of 81.1 per cent was recorded at 07:14 hours and 60.9 per cent was recorded at 14:14 hours with mean sunshine hours of 5.5 hours day^{-1}.

Treatment details and crop management

Short duration rice variety Co 54 was selected for the study. Experiment was carried out in a split-plot design with three main plots and seven sub plots comprising 21 treatment combinations and was replicated thrice. The treatment details are as follows. Main plot consists of three irrigation methods such as irrigation with the help of field water tube at 15 cm depletion level (M_1), alternate wetting and drying (M_2) and conventional flooding (M_3). Nutrient management practices were assisted in sub plots *viz*., application of 50 per cent basal N + foliar spray of nano urea (S_1), application of 75 per cent basal N + foliar spray of nano urea (S_2), application of 50 per cent basal K + foliar spray of nano potash (S_3), application of 75 per cent basal K + foliar spray of nano potash (S_4), application of 50 per cent basal N and K + foliar spray of nano urea and nano potash (S_5), 100 percent recommended fertilizer schedule of 120:40:40 kg ha^{-1} (S_6) and absolute control (S_7). Entire P was applied as basal whereas N and K were applied in three splits. Foliar spray was given @ 4 ml/litre of water at active tillering and at panicle initiation stages. Transplanting was done with 21 days old seedlings.

Imposition of irrigation treatments

In conventional flooding method, water was stagnated up to 10 days prior to harvest. For alternate wetting and drying method, irrigation was given after hair line crack appearance in soil. Irrigation through field water tube was given through PVC pipe of 30 cm length and 15 cm diameter. 15 cm length of the pipe was perforated with 0.5 cm diameter. Perforated side of the tube was inserted into the field and soil accumulated inside the tube was removed periodically.

Observations

Growth parameters such as plant height, tillers m^{-2} and dry matter production (kg ha^{-1}) was recorded at active tillering, panicle initiation and at harvest stages. Physiological characters like LAI and CGR was calculated for each treatment combinations with the below mentioned formula. Grain and straw yield was computed for each treatment after harvest.

LAI

Leaf area index was computed for active tillering, panicle initiation and at harvest stage as proposed by Palanisamy and Gomez (1974).

$$LAI = \frac{L \times B \times K \times \text{Total leaves plant}^{-1}}{\text{Plant spacing}}$$

Where,
L = Maximum length of 3rd leaf from the top.
B = Maximum breadth of the same leaf.
K = Constant factor (0.75).

CGR

Crop growth rate was estimated as suggested by Watson (1958) and expressed in kg ha^{-1} day^{-1}.

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

Where,
W_1 and W_2 were DMP in kg ha^{-1} at times t_1 and t_2, respectively.

Statistical analysis

Data analysis was done with R software version 4.2.1 to find out the significant treatment difference at 5 per cent probability level. The relationship between growth and physiological parameters with yield was assessed by Pearson correlation analysis using SPSS software version 16.0.

RESULTS AND DISCUSSION

Data pertaining to growth parameters like plant height, tillers, DMP were presented in Table 1 to 3. The data in Table 4 was mentioned for LAI and Table 5 for CGR. Yield data is represented in Table 6.

Plant height

Effect of irrigation methods

Plant height was increased as the growth advances and reached maximum at harvest stage. Among the irrigation methods, plant height was higher in alternate wetting and drying method (M_2) of about 48.8, 63.4 and 104.1 cm at all the stages. It was followed by conventional flooding (M_3) which recorded 46.1, 59.7 and 97.8 cm. Plant height plays a vital role in capturing solar radiation and several researchers have found increased plant height under optimal irrigation regime. Favourable environment under AWD stimulated cell division and stem elongation which in turn influenced the plant height. Similar result was noticed by Kannan *et al*. (2017) and also with Rahaman and Sinha (2013). Irrigation given with field water tube when water level depletes below 15 cm from soil surface (M_1) recorded minimum plant height (39.3, 48.7 and 86.6 cm) than other treatments which might be due to increased water stress condition. Mote *et al*. (2017) reported similar result from their findings.

Table 1: Effect of irrigation and nutrient management strategies on plant height (cm) of rice.

Treatments	Active tillering				Panicle initiation				At harvest			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	39.9	47.2	45.7	44.3	45.7	59.1	55.4	53.4	87.2	103.6	96.9	95.9
S_2	44.5	57.2	54.7	52.1	56.9	77.6	72.7	69.1	88.1	109.1	104.2	100.5
S_3	38.4	49.6	47.1	45.0	45.1	61.7	58.0	54.9	87.1	102.8	95.8	95.2
S_4	42.1	50.7	48.7	47.2	54.0	67.9	64.9	62.3	90.6	109.1	100.8	100.2
S_5	42.1	51.8	48.7	47.5	54.3	73.4	69.4	65.7	95.1	115.4	111.7	107.4
S_6	40.3	50.9	46.1	45.8	52.5	64.3	60.2	59.0	92.0	108.8	100.5	100.4
S_7	27.8	34.5	31.6	31.3	32.4	40.1	37.1	36.5	65.8	79.9	74.4	73.4
Mean	39.3	48.8	46.1		48.7	63.4	59.7		86.6	104.1	97.8	
	M	**S**	**M at S**		**M**	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	1.2	1.1	1.3		1.8	1.7	2.4		2.8	2.8	2.8	
CD (P=0.05)	2.6	2.4	2.7		3.3	3.1	5.2		6.1	6.0	6.2	

Table 2: Effect of irrigation and nutrient management strategies on tiller production (m^{-2}) of rice.

Treatments	Active tillering				Panicle initiation				At harvest			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	151	207	203	187	214	284	268	255	254	338	317	303
S_2	174	259	244	226	247	366	349	321	283	419	383	362
S_3	150	202	195	182	201	265	253	240	240	317	303	287
S_4	154	221	214	196	216	309	304	276	256	372	351	326
S_5	168	248	226	214	238	344	314	299	291	447	427	388
S_6	152	215	209	192	216	297	284	266	258	351	339	316
S_7	93	115	105	104	116	163	149	143	138	182	170	163
Mean	149	210	199		207	290	274		246	347	327	
	M	**S**	**M at S**		**M**	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	5.07	4.6	5.09		7.2	6.6	8.13		8.7	8.4	9.9	
CD (P=0.05)	10.86	10.0	10.91		15.4	14.3	17.4		19.1	18.2	21.2	

Effect of nutrient management practices

Plant height was maximum (52.1 and 69.1 cm) with application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) active tillering and at panicle initiation stage. It was followed by 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) which recorded 47.5 and 65.7 cm at both stages. At harvest stage, application of 50 percent basal N and K + foliar spray of nano urea and nano potash at critical stages (S5) recorded maximum plant height (107.4 cm) and was followed by 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) which recorded 100.5 cm of plant height. Enhanced cell growth as influenced by the foliar application of nano fertilizers, increased the height of the plant. Besides it supplies sufficient nutrient for a prolonged period throughout the crop's growth. Similar result was noted by Samui *et al*. (2022) in maize crop and by Bahubhai *et al*. (2019). Plant height was obtained minimum (31.3, 36.5 and 73.4 cm) with absolute control plot (S_7). This could be due to insufficient nutrient supply to the crop at all stages.

Interactional effect of irrigation and nutrient management practices

On interaction, at active tillering and panicle initiation stages, alternate wetting and drying coupled with application of 75 per cent basal N + foliar spray of nano urea at critical stages (M_2S_2) recorded maximum plant height of 57.2 and 77.6 cm. At harvest stage, alternate wetting and drying with application of 50 percent basal N and K + foliar spray of nano urea and nano potash at critical stages (M_2S_5) recorded maximum plant height (115.4 cm) than other treatment combinations. Optimum availability of water and nutrients provided through intermittent irrigation and foliar application of nano fertilizers influenced the photosynthetic process enhanced the height of the plant. This was in accordance with Jayakumar *et al*. (2004). While it was minimum with irrigation at 15 cm depletion from the soil surface with no fertilizer applied plot (M_1S_7) at all stages (27.8, 32.4 and 65.8 cm). Prolonged water stress and unavailability of nutrient might be the reason for minimum plant height.

Number of tillers m^{-2}

Effect of irrigation method

Irrigation method had a positive impact on number of tillers m^{-2}. It was maximum at alternate wetting and drying method (M_2) (210, 290 and 347 tillers m^{-2}) followed by conventional flooding (M_3) which recorded 199, 274 and 327 tillers m^{-2} at all the three stages. Favourable environment provided by adequate availability of water supply enhanced the tiller growth by better absorption, translocation and assimilation of nutrients by plants. It was recorded lower at irrigation with field water tube when water level depletes below 15 cm from soil surface (M_1) (149, 207 and 246 tillers m^{-2}). Development of water stress under this condition reduced plant height, LAI and thus the amount of PAR. Leaf elongation is the most sensitive process altered by water stress which in turn reduce the number of potentially active sites for tillering. Since during tillering, plant produces more leaves and due to water stress, leaf initiation gets affected which in turn reduce the number of tillers. These results are in tune with findings of Sathish *et al*. (2017) and Kumar *et al*. (2014).

Effect of nutrient management practices

Among varied nutrient management practices at active tillering and panicle initiation stage, application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) recorded maximum tillers of 226 and 321 $m^{-2.}$ It was followed by application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) (214 and 299 tillers m^{-2}). At harvest stage, application of 50 percent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) recorded maximum no. of tillers m^{-2} (388) and was followed by 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) which recorded 362 tillers m^{-2}. Nano fertilizers have a dimension range of 30-40 nm and due to their higher surface area and slow release pattern they met the crop's nutrient demand in a timely manner. This attributed for maximum tiller growth. While no. of tillers m^{-2} was obtained minimum with absolute control (S_7) (104, 143 and 163 tillers m^{-2}) at all stages.

Interactional effect of irrigation and nutrient management practices

On interaction, at active tillering and panicle initiation stages, alternate wetting and drying along with application of 75 per cent basal N + foliar spray of nano urea at critical

Table 3: Effect of irrigation and nutrient management strategies on dry matter production (kg ha^{-1}) of rice.

Treatments	Active tillering				Panicle initiation				At harvest			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S1	1986	2642	2494	2374	4437	5874	5549	5287	6613	8864	8309	7929
S2	2292	3418	3267	2993	5122	7581	7322	6675	7348	10821	9941	9370
S3	1864	2473	2367	2234	4148	5497	5281	4975	6203	8302	7772	7426
S4	2004	2846	2726	2525	4477	6769	6238	5828	6676	9620	9117	8471
S5	2209	3142	2813	2721	4935	7115	6567	6206	7631	11489	10933	10018
S6	2002	2764	2700	2489	4465	6278	6140	5628	6660	9118	9033	8270
S7	1123	1514	1384	1340	2532	3340	3090	2987	3768	5067	4497	4444
Mean	1926	2686	2536		4302	6065	5741		6414	9040	8515	
	M	**S**	**M at S**		**M**	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	69.2	69.8	71.5		150.1	138.6	167.8		243.7	228.0	249.5	
CD (P=0.05)	148.2	139.6	153.1		321.2	296.7	359.1		521.5	487.9	533.9	

Table 4: Effect of irrigation and nutrient management strategies on leaf area index of rice.

Treatments	Active tillering				Panicle initiation				At harvest			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	1.91	2.47	2.33	2.24	2.62	3.31	3.26	3.06	1.90	2.52	2.38	2.26
S_2	2.24	3.11	2.97	2.77	3.04	4.20	3.98	3.74	2.11	3.10	2.76	2.66
S_3	1.84	2.31	2.21	2.12	2.56	3.25	3.07	2.96	1.78	2.35	2.26	2.13
S_4	2.15	2.62	2.52	2.43	2.79	3.48	3.30	3.19	1.91	2.72	2.64	2.42
S_5	2.21	2.90	2.60	2.57	2.91	3.87	3.44	3.41	2.19	3.26	3.11	2.85
S_6	1.98	2.53	2.45	2.32	2.71	3.41	3.33	3.15	1.91	2.69	2.58	2.40
S_7	1.13	1.39	1.26	1.26	1.52	1.87	1.70	1.70	1.17	1.44	1.30	1.30
Mean	1.92	2.48	2.33		2.59	3.34	3.15		1.85	2.58	2.43	
	M	**S**	**M at S**		**M**	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	0.06	0.05	0.07		0.08	0.07	0.10		0.06	0.06	0.07	
CD (P=0.05)	0.13	0.12	0.15		0.18	0.17	0.23		0.14	0.13	0.16	

stages (M_2S_2) recorded maximum (259 and 366) tillers m^{-2}. Alternate wetting and drying with application of 50 percent basal N and K + foliar spray of nano urea and nano potash at critical stages (M_2S_5) recorded maximum no. of tillers m^{-2} (447 tillers m^{-2}) than other treatment combinations at harvest stage. Better aeration provided by the AWD regime foliar application of nano fertilizers increased uptake of nutrients which results in better source sink conversion which ascribed higher growth parameters. While it was minimum (93, 116 and 138 tillers m^{-2}) at irrigation at 15 cm depletion from the soil surface with absolute control plot (M_1S_7).

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

Effect of irrigation method

Dry matter accumulation followed an increasing trend and was maximum at harvest stage. Dry matter production was maximum (2686, 6065 and 9040 kg ha^{-1}) at alternate wetting and drying method (M_2) followed by farmer's practice *i.e.* conventional flooding (M_3) which recorded 2536, 5741 and 8515 kg ha^{-1} at all stages. Sufficient moisture supply enhanced the uptake of nutrients thereby influencing the biomass growth. It enhanced the plant height, tiller numbers and resulted in higher dry matter production. This is similar to the findings of Jayakumar *et al*. (2004). Dry matter was recorded lower at irrigation at 15 cm depletion with field water tube when water level depletes to 15 cm below from soil surface (M_1) of about 1926, 4302 and 6414 kg ha^{-1} at all stages.

Effect of nutrient management practices

Among varied nutrient management practices, application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) recorded maximum dry matter production (2993 and 6675 kg ha^{-1}) at active tillering and panicle initiation stage. It was followed by application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) 2721 and 6206 kg ha^{-1}. At harvest stage, dry matter accumulation was maximum with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) (10018 kg ha^{-1}) and was followed by 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) (9370 kg ha^{-1}). Slow release, rapid absorption and penetration of nano nutrients by plants facilitate the utilization of nano fertilizers readily and completely. This led to higher biomass accumulation.

Table 5: Effect of irrigation and nutrient management strategies on crop growth rate (kg ha^{-1} day^{-1}) of rice.

Treatments	Active tillering - panicle initiation				Panicle initiation - Harvest			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	116.7	153.9	145.5	138.7	65.9	90.6	83.6	80.1
S_2	134.8	198.2	193.1	175.4	67.5	98.2	79.4	81.7
S_3	108.8	144.0	138.8	130.5	62.3	85.0	75.5	74.3
S_4	117.8	186.8	167.2	157.3	66.6	86.4	87.2	80.1
S_5	129.8	189.2	178.8	165.9	81.7	132.5	132.3	115.5
S_6	117.3	167.3	163.8	149.5	66.5	86.1	87.7	80.1
S_7	67.1	87.0	81.2	78.4	37.5	52.3	42.6	44.1
Mean	113.2	160.9	152.6		64.0	90.2	84.0	
	M	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	3.8	3.5	3.9		2.1	2.7	2.4	
CD (P=0.05)	8.2	7.6	8.4		4.6	5.9	5.1	

Table 6: Effect of irrigation and nutrient management strategies on grain yield (kg ha^{-1}), straw yield (kg ha^{-1}) of rice.

Treatments	Grain yield (kg ha^{-1})				Straw yield (kg ha^{-1})			
	M_1	M_2	M_3	Mean	M_1	M_2	M_3	Mean
S_1	3370	4478	4226	4025	4482	6045	5667	5398
S_2	3745	5344	4945	4678	4985	7198	6636	6273
S_3	3159	4180	4011	3783	4198	5643	5379	5074
S_4	3400	4830	4695	4308	4529	6521	6305	5785
S_5	3887	5797	5461	5048	5209	7826	7355	6797
S_6	3394	4791	4593	4259	4528	6458	6200	5729
S_7	2074	2568	2346	2329	2763	3467	3146	3125
Mean	3290	4570	4325		4385	6166	5813	
	M	**S**	**M at S**		**M**	**S**	**M at S**	
S.Ed	81.94	117.36	205.27		110.50	161.01	280.85	
CD (P=0.05)	227.51	238.06	440.83		306.82	326.59	602.20	

Chandana *et al*. (2021) reported similar result. Dry matter accumulation was obtained minimum at active tillering (1340 kg ha^{-1}), panicle initiation (2987 kg ha^{-1}) and at harvest stage (4444 kg ha^{-1}) with absolute control plot (S_7).

Interactional effect of irrigation and nutrient management practices

Alternate wetting and drying combined with application of 75 per cent basal N + foliar spray of nano urea at critical stages (M_2S_2) recorded higher dry matter production of about 3418 and 7581 kg ha^{-1} at active tillering and panicle initiation stages. At harvest stage alternate wetting and drying combined with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (M_2S_5) recorded maximum dry matter production (11489 kg ha^{-1}). While it was minimum with irrigation at 15 cm depletion from the soil surface along with absolute control (M_1S_7) at all stages (1123, 2532 and 3768 kg ha^{-1}).

Leaf area index

Effect of irrigation method

Leaf area index is an important character which eventually determines the crop's productivity since it influences the light interception and transpiration. It serves as an indicator for total photosynthetic area available to plants for production of photosynthates and its accumulation at various parts (Fageria *et al*., 2006). Alternate wetting and drying method (M_2) recorded maximum LAI at active tillering, panicle initiation and at harvest stage (2.48, 3.34 and 2.58). It was followed by conventional flooding (M3) which recorded 2.33, 3.15 and 2.43 at all stages. It was minimum at irrigation with the help of field water tube at 15 cm depletion of water level (M_1) (1.92, 2.59 and 1.85).

Effect of nutrient management practices

Optimum and adequate supply of water influenced the growth and number of leaves which consequently resulted in increased LAI. Leaf area index was decreased at harvest stage due to senescence and drying of leaves. At active tillering and panicle initiation stage, LAI was maximum with application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) (2.77 and 3.74). It was followed by application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) which recorded LAI of about 2.57 and 3.41. At harvest stage, LAI was maximum with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) of about 2.85. It was followed by application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) which recorded LAI of about 2.66. Combined application of conventional fertilizers and foliar spray of nano urea promoted higher plant height thereby improving the light interception, adsorption and utilization of solar radiation. In addition, higher availability of nutrients enhanced the cell division by improved absorption and translocation of nutrients through stomata which resulted in higher leaf area index. Similar result was noted by Ajithkumar *et al*. (2021). LAI was minimum (1.26, 1.70 and 1.30) with absolute control plot (S_7).

Interactional effect of irrigation and nutrient management practices

Alternate wetting and drying combined with application of 75 per cent basal N + foliar spray of nano urea at critical stages (M_2S_2) recorded higher LAI of about 3.11 and 4.20 at active tillering and panicle initiation stage. At harvest stage alternate wetting and drying combined with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (M_2S_5) recorded maximum LAI (3.26). Proper soil moisture condition and combined fertilization ensured steady supply of nutrients to the plant which led to longer and wider leaves, enhanced the interception and utilization of solar radiation thus led to maximum LAI under this treatment combination. Similar result was reported by Kannan *et al*. (2017). While it was minimum with irrigation at 15 cm depletion from the soil surface along with absolute control (M_1S_7) at all stages (1.13, 1.52 and 1.17).

Crop growth rate (kg ha^{-1} day^{-1})

Effect of irrigation method

Crop growth rate was maximum under alternate wetting and drying method (M_2) 160.9 and 90.2 kg ha^{-1} day^{-1} from active tillering to panicle initiation stage and panicle initiation to harvest stage. It was followed by conventional flooding (M_3) which recorded 152.6 and 84.0 kg ha^{-1} day^{-1}. Sufficient moisture level, better root growth and enhanced leaf area have increased the growth of above ground parts and thereby enhanced the CGR. Similar finding was

Table 7: Correlation between growth, physiological characters and yield of rice.

	PH	Tillers	DMP	LAI	GY	SY
PH	1	0.970**	0.971**	0.969**	0.971**	0.972**
Tillers	0.970**	1	0.999**	0.998**	0.997**	0.997**
DMP	0.971**	0.999**	1	0.998**	0.998**	0.998**
LAI	0.969**	0.998**	0.998**	1	0.999**	0.999**
GY	0.971**	0.997**	0.998**	0.999**	1	1.000**
SY	0.972**	0.997**	0.998**	0.999**	1.000**	1

**Correlation is significant at the 0.01 level (2-tailed).

PH - Plant height; DMP - Dry matter production; LAI - Leaf area index; GY - Grain yield; SY - Straw yield.

reported by Duvvada *et al*. (2020) and Selvakumar *et al*. (2020). CGR was obtained minimum with irrigation with the help of field water tube at 15 cm depletion of water level (M_1) (113.2 and 64.0 kg ha^{-1} day^{-1}).

Effect of nutrient management practices

Among varied nutrient management practices, application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) recorded maximum crop growth rate of about 175.4 kg ha^{-1} day^{-1} at active tillering-panicle initiation stage. It was followed by application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) which recorded 165.9 kg ha^{-1} day^{-1}. At panicle initiation - harvest stage, application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5) recorded maximum crop growth rate (115.5 kg ha^{-1} day^{-1}) and was followed by application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) (81.7 kg ha^{-1} day^{-1}). Crop growth rate is considered as an interaction between plant and environment. CGR is directly proportional to the biomass accumulation. Adequate and prolonged availability of nutrients turned up for better translocation of assimilates and photosynthates to various parts of the plant. This led to higher accumulation of biomass thus resulted in higher crop growth rate. Arya (2022) and Chavan (2019) reported higher crop growth rate with foliar spray of nano fertilizers. Crop growth rate was minimum (78.4 and 44.1 kg ha^{-1} day^{-1}) with absolute control plot (S_7) at all stages.

Interactional effect of irrigation and nutrient management practices

With interactional effect, at active tillering-panicle initiation stage crop growth rate was maximum with alternate wetting and drying along with application of 75 per cent basal N + foliar spray of nano urea at critical stages (M_2S_2) which recorded 198.2 kg ha^{-1} day^{-1}. From panicle initiation -harvest stage alternate wetting and drying combined with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (M_2S_5) which recorded 132.5 kg ha^{-1} day^{-1}. Availability of nutrients under optimum moisture condition improved the uptake of nutrients, its translocation and assimilation of photosynthates enhanced higher biomass production which turned up for higher crop growth rate. It was minimum (67.1 and 37.5 kg ha^{-1} day^{-1}) under irrigation at 15 cm depletion from the soil surface along with absolute control (M_1S_7) at all stages.

Yield

Effect of irrigation method

Irrigation methods had significant impact over grain and straw yield of rice. Grain and straw yield of rice was obtained maximum (4570 and 6166 kg ha^{-1}) due to favourable condition provided by alternate wetting and drying (M_2). This could be due to effective nutrient uptake under adequate moisture supply which reflected higher accumulation of dry matter thus resulted in higher yield. It was closely followed by conventional flooding (M_3) which recorded grain and straw yield of about 4325 and 5813 kg ha^{-1}. Increased water stress influenced partial closing of stomata which re tricted the entry of CO_2 Scarcity of water and CO_2 hampered photosynthetic process which resulted in poor translocation and accumulation of photosynthates which reduced both grain (3290 kg ha^{-1}) and straw yield (4385 kg ha^{-1}) under irrigation with 15 cm depletion of water level in FWT (M_1). Similar result was confirmed by Arivukkumar *et al*. (2021).

Effect of nutrient management practices

Combined application of conventional and nano fertilizers have a considerable impact over yield attributes which was reflected in yield. Among the different nutrient management practices, grain and straw yield was recorded maximum (5048 and 6797 kg ha^{-1}) with application of 50 per cent basal N and K + foliar spray of nano urea and nano potash at critical stages (S_5). Foliar spray of nano N facilitated the uptake by plants as these nano particles penetrate through stomatal opening influencing the uptake by crops and increasing the nutrient use efficiency (Velmurugan *et al*., 2021). Further Nano K when given as foliar spray might have enhanced the yield attributing characters which in turn increased the grain yield. Similar result was obtained by Lekshmi *et al*. (2022). It was followed by application of 75 per cent basal N + foliar spray of nano urea at critical stages (S_2) which recorded 4678 and 6273 kg $ha^{-1}$of grain and straw yield. Grain and straw yield was minimum (2329 and 3125 kg ha^{-1}) with absolute control (S_7).

Interactional effect of irrigation method and nutrient management practices

Both irrigation methods and nutrient management practices had considerable influence on yield of rice. Maximum yield was obtained with alternate wetting and drying irrigation method along with the application of 50 per cent N and K through fertilizer + Nano N and K as foliar spray (M_2S_5) (5797 and 7826 kg ha^{-1}). Due to better physico-chemical environment provided under this treatment combination encouraged the production of growth and yield attributes which was reflected in maximum grain and straw yield. Similar result was reported by Jayakumar *et al*. (2004). Both grain and straw yield were minimum (2074 and 2763 kg ha^{-1}) with irrigation at 15 cm depletion level from the soil surface with absolute control (M_1S_7). Insufficient moisture and nutrient supply declined the growth and yield characters which hampered the grain and straw yield. This is in accordance with finding of Kumar *et al*. (2014).

Correlation analysis

Correlation (Table 7) was carried out with 1 per cent probability level. Positive correlation was observed between growth, physiological attributes with yield of transplanted rice crop.

CONCLUSION

Based on the above findings, it was concluded that alternate wetting and drying method along with combination of conventional fertilizers and foliar application of nano fertilizers resulted in maximum growth and physiological characters of transplanted rice in addition to grain and straw yield.

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Conflict of interest

All authors declared that there is no conflict of interest.

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