Indian Journal of Agricultural Sciences **94** (4): 339–344, April 2024/Article
https://doi.org/10.56093/ijas.v94i4.143367

Influence of deficit irrigation and nano NK application on root dynamics, physiology and WUE of transplanted rice (*Oryza sativa*)

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Received: 06 October 2023; Accepted: 04 January 2024

ABSTRACT

A field experiment was conducted during the rainy (*kharif*) (June–September, 2022) and winter (*rabi*) (December 2022–March, 2023) seasons at Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Madurai, Tamil Nadu to study the effect of irrigation methods and nutrient management strategies on the growth of roots, physiological aspects, yield and water use efficiency of transplanted rice (*Oryza sativa* L.). Experiment was conducted in a split-plot design comprised of 3 irrigation methods, viz. Irrigation at 15 cm depletion of water level in field water tube (M_1); Alternate wetting and drying (M_2); Conventional flooding (M_3) in main plot and 7 nutrient management strategies, viz. Application of 50% N + nano urea as foliar spray (S_1); 75% N + nano urea as foliar spray (S_2); 50% K + nano potash as foliar spray (S_3); 75% K + nano potash as foliar spray (S_4); 50 and 75% N and K + nano urea and potash as foliar spray (S_5); 100% RDF (S_6); and absolute control (S_7) in sub plot, replicated thrice. Results indicated that under M_1S_2, root characteristics like length, volume and dry weight were notably higher. Physiological attributes such as stomatal conductance, transpiration and photosynthetic rate recorded high with M_2S_5. However, the maximum yield and water use efficiency were observed with M_2S_5. In conclusion, the treatment combination M_2S_5 is considered as practical recommendation for farmers in the Periyar Vaigai command area, ensuring optimal yield while economically utilizing water and fertilizers.

Keywords: Irrigation, Nano NK, Nutrient, Rice, Water use efficiency

Rice (*Oryza sativa* L.) consumption has exceeded 50 kg per capita annually, with Asia alone contributing to 87% of the total cultivation area and consuming 90% of the global rice production (FAO 2018). Specifically, in Tamil Nadu, rice cultivation spans 2.03 Mha, resulting in production of 6.8 Mt with a productivity of 3.3 t/ha (Indiastat 2021). To address the challenge of feeding a growing population amidst water scarcity, it's imperative to enhance food production and modify farming practices (Maneepitak *et al*. 2019). Various approaches, including aerobic rice, drip irrigation and sprinkler irrigation have been developed to boost yields. Despite the substantial benefits observed in drip and sprinkler irrigation, their adoption remains limited among small and marginal farmers. Though aerobic rice is an efficient water saving practice, it has low yield potential than lowland rice. Alternate wetting and drying method is being favoured by resource-limited farmers, conserves 15–30% of water, either maintaining or increasing yields compared to conventional method (Ishfaq *et al*. 2020). Field water tube method effectively schedule irrigation under alternate wetting and drying, preventing crop over drying. Scientists at IRRI have established a safe threshold limit of a 15 cm water level depletion below which rice crop yields are adversely affected (Prithiwiraj 2017).

Fertilizers play a vital role in increasing the productivity, with nitrogen and potassium significantly influencing crop growth and quality. The efficacy of applied nitrogen and potassium fertilizers is approximately 30–40% and 40–50% respectively (Azam *et al*. 2022). Smart fertilizers like nano fertilizers have substantial potential in enhancing crop yield and fertilizer use efficiency (Anjuman *et al*. 2017). Nano urea, for instance, elevates crop yield by 8% and nitrogen use efficiency to 80% compared to conventional urea (Namasharma *et al*. 2023). Considering these factors, present experiment was planned to study the impact of water-saving irrigation methods and nano NK fertilizers on the productivity of transplanted rice.

MATERIALS AND METHODS

Field experiment was conducted during rainy (*kharif*) (June–September, 2022) and winter (*rabi*) (December

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2022–March, 2023) seasons at Agricultural College and Research Institute (Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu), Madurai (9°54'N and 78°54'E with an altitude of 147 m amsl), Tamil Nadu. The soil was sandy clay loam, medium in available nitrogen (241.2 and 213.4 kg/ha); phosphorus (16.2 and 16.4 kg/ha) and high in available potassium (332.5 and 341.5 kg/ha) in both the seasons. During *kharif*, a total of 414.5 mm rainfall was received in 19 rainy days with an average relative humidity (RH) of 83.5%. The mean maximum and minimum temperature were 34.7°C and 24.2°C respectively. During *rabi*, total rainfall received was about 49.6 mm in 7 rainy days with average RH of 90.5%. The average maximum and minimum temperature recorded were 31.9°C and 22.1°C respectively. Short duration rice variety Co 54 with duration of 110–115 days was used as test crop during both the seasons. The experiment was designed in split-plot having 3 irrigation methods, viz. Irrigation at 15 cm depletion of water level in field water tube (M_1); Alternate wetting and drying (M_2); Conventional flooding (M_3) in main plot and 7 nutrient management strategies, viz. Application of 50% N + nano urea as foliar spray (S_1); 75% N + nano urea as foliar spray (S_2); 50% K + nano potash as foliar spray (S_3); 75% K + nano potash as foliar spray (S_4); 50 and 75% N and K + nano urea and potash as foliar spray (S_5); 100% RDF (S_6); and absolute control (S_7) in sub plot, replicated thrice. Individual plots with a dimension of 5 m × 5 m was formed with irrigation channels and buffer channels (1 m width) and levelled thoroughly. The net plot size was 4.6 m × 4.6 m.

Normal irrigation practice (5 cm depth) was given up to 10 DAT (days after transplanting) for better establishment of crop and thereafter irrigation was provided as per treatments. Irrigation through field water tube (FWT) was given through PVC pipe of 30 cm length and 15 cm diameter. Bottom of the pipe (15 cm) was perforated with 0.5 cm diameter. Perforated side of the tube was inserted into the field and soil accumulated inside was removed periodically. For alternate wetting and drying method (AWD), irrigation was given after hairline crack appearance in surface soil. In conventional flooding, water was stagnated up to 5 cm water depth. Recommended dose of fertilizer (RDF) of 120:40:40 kg NPK/ha was followed during both the seasons as per TNAU CPG (2020). Nutrients were applied as basal (100% P and 50% N and K), 25 DAT (25% N and K) and at 45 DAT (25% N and K) in the form of urea, diammonium phosphate (DAP) and muriate of potash (MOP). Foliar spray of nano N and K fertilizers was given @4 ml/litre of water at active tillering and panicle initiation stage.

Seed rate adopted was 60 kg/ha and 21-days seedlings were transplanted from nursery to main field. In *kharif* season, transplanting was done on 11th July 2022 and crop was harvested on 08th October 2022. During *rabi,* seedlings were transplanted on 11th January 2023 and harvested on 03rd April 2023. Pre-emergence herbicide, viz. Bensulfuron Methyl 0.6% + Pretilachlor 6% was applied on 3 DAT. Early post emergence herbicide Bispyripac sodium was sprayed on 15 DAT followed by one hand weeding on 45 DAT.

Root characters such as length (cm), volume (cc/hill) and dry weight (g) were measured for each treatment combinations. Physiological attributes such as transpiration rate (µmol/m^2/sec), photosynthetic rate (mol/m^2/sec) and stomatal conductance (mol/m^2/sec) were recorded using portable photosynthetic system (Model LC *Pro* T, ADC Bioscientific Ltd) equipped with choice of integrated light units fitted with GPS. Leaves were inserted in a 3 cm^2 leaf chamber for assessing above physiological parameters. Grain and straw yield were recorded from the net plot area and expressed in kg/ha. Water use efficiency (WUE) was worked out as suggested by Viets (1962):

$$\text{WUE} = \frac{\text{Yield (kg/ha)}}{\text{Total water use (mm)}}$$

To compare the difference among treatment combinations, data analyses was done with R software version 4.2.1 at 5% probability level as suggested by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Root morphology parameters: Root length and volume reveals the root system's soil contact, aiding the absorption of water and nutrients, promoting shoot photosynthesis. Higher root dry weight enhances the resources availability fostering photosynthetic accumulation. All the root parameters were found maximum with treatment M_1 during *kharif* and *rabi* of about 24.9 and 22.5 cm length, volume of 23.6 cc and 21.8 cc/hill (Table 1). While treatment M_3 recorded 17.7 and 15.3 cm of length and 16.9 and 15.7 cc/hill of volume. Treatment M_1 recorded 7.059 and 6.865 g and M_3 recorded 6.011 and 5.627 g of root dry weight in both seasons. AWD method improves aeration, facilitating root access to water and oxygen. Similar results were reported by Sathish *et al*. (2017) in which they observed increased root volume with irrigation at 5 cm depletion of water level in FWT.

Among nutrient management strategies, treatment S_2 recorded maximum root length of 25.6 and 21.0 cm, root volume of 23.9 and 22.5 cc/hill along with root dry weight of 7.534 and 7.460 g in both seasons (Table 1). This could be due to adequate supply of N at basal which might have promoted better root growth. Wang *et al*. (2022) observed maximum root attributes under adequate supply of nitrogen at the initial stage of about 60% N applied as basal.

With interaction, M_1S_2 surpassed other treatment combinations by recording root length of 31.2 and 25.7 cm, root volume of 27.7 and 26.1 cc/hill, root dry weight of 8.230 and 8.210 g during both the seasons respectively.

Physiological attributes: Transpiration rate (5.19 and 4.98 mol/m^2/sec) and photosynthetic rate (19.4 and 18.1 µmol/m^2/sec) were observed high under treatment M_2 while minimum with M_1 (4.39 and 4.29 mol/m^2/sec) (14.4 and 13.6 µmol/m^2/sec) in *kharif* and *rabi* season during panicle initiation stage (Table 2). Stomatal conductance of about 0.28 and 0.27 mol/m^2/sec were registered under M_2

Table 1 Effect of water saving irrigation methods and nano NK application on root dynamics of transplanted rice

Treatment	Root length (cm)		Root volume (cc/hill)		Root dry weight (g)	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
M						
M_1	24.9	22.5	23.6	21.8	7.059	6.865
M_2	21.8	19.7	21.7	20.2	6.659	6.369
M_3	17.7	15.3	16.9	15.7	6.011	5.627
SEd	0.71	0.61	0.67	0.66	0.196	0.192
CD (P=0.05)	1.53	1.31	1.43	1.30	0.424	0.410
S						
S_1	20.7	18.3	19.2	18.3	6.047	5.764
S_2	25.6	21.0	23.9	22.5	7.534	7.460
S_3	20.9	19.0	20.5	18.1	6.473	5.982
S_4	22.1	20.6	22.5	21.1	7.008	6.926
S_5	21.5	19.5	20.6	19.3	6.645	6.391
S_6	20.7	19.2	20.4	19.0	6.413	6.321
S_7	18.7	16.7	18.1	16.5	5.705	5.164
SEd	0.76	0.65	0.70	0.65	0.203	0.203
CD (P=0.05)	1.63	1.39	1.49	1.39	0.438	0.434
M × S						
M_1S_1	24.9	21.7	21.4	20.0	6.357	6.543
M_1S_2	31.2	25.7	27.7	26.1	8.230	8.210
M_1S_3	25.3	21.3	24.3	20.3	6.857	6.303
M_1S_4	26.0	23.7	26.1	24.6	7.587	7.555
M_1S_5	23.5	24.2	23.1	21.7	7.646	6.812
M_1S_6	23.3	22.4	22.9	21.5	6.802	6.756
M_1S_7	20.3	18.7	20.0	18.7	5.934	5.873
M_2S_1	20.6	18.6	20.2	18.9	6.000	5.628
M_2S_2	25.8	20.1	25.5	24.0	7.753	7.724
M_2S_3	19.5	20.7	19.2	18.2	6.665	5.939
M_2S_4	22.1	21.8	23.6	22.2	7.020	6.979
M_2S_5	22.8	18.9	22.4	21.0	6.331	6.617
M_2S_6	22.3	20.3	21.9	20.6	6.521	6.470
M_2S_7	19.4	17.6	19.2	16.8	5.694	5.223
M_3S_1	16.7	14.7	16.1	15.9	5.784	5.121
M_3S_2	19.9	17.1	18.6	17.3	6.618	6.445
M_3S_3	17.9	14.9	17.9	15.7	5.897	5.702
M_3S_4	18.2	16.4	17.9	16.7	6.417	6.244
M_3S_5	18.1	15.5	16.2	15.1	5.957	5.745
M_3S_6	16.5	14.8	16.2	15.1	5.918	5.737
M_3S_7	16.4	13.8	15.1	14.0	5.485	4.397
SEd	0.79	0.65	0.71	0.66	0.206	0.206
CD (P=0.05)	1.69	1.40	1.51	1.42	0.445	0.441

Treatment details are given under Materials and Methods.

and 0.24 and 0.23 mol/m^2/sec with M_1. The presence of adequate water enhanced the nutrient uptake thus promoted higher transpiration rate, photosynthetic rate and stomatal conductance.

Transpiration and photosynthetic rate of about 4.94 and 4.74 mol/m^2/sec; 17.0 and 16.5 µmol/m^2/sec were maximum under S_2 and minimum with S_7 treatment (Table 2). Optimum application of nitrogen can elevate both photosynthetic and transpiration rate. It can also improve the ability of mesophyll cells to assimilate CO_2 within the leaf to maximize the accumulation of dry matter production. Whereas stomatal conductance was recorded maximum with S_4 (0.27 and 0.26 mol/m^2/sec). Adequate potassium levels can help to regulate the opening and closing of stomata which have an influence over plant's water balance and overall physiology. Regarding interaction, M_2S_2 resulted in higher transpiration rate (5.31 and 5.26 mol/m^2/sec), photosynthetic rate (19.81 and 18.84 µmol/m^2/sec) and M_2S_4 resulted in higher stomatal conductance (0.26 and 0.26 mol/m^2/sec). Whereas M_1S_7 attributed minimum transpiration rate (4.25 and 4.22 mol/m^2/sec), photosynthetic rate (14.31 and 13.32 µmol/m^2/sec) and stomatal conductance (0.22 and 0.18 mol/m^2/sec). Guo *et al*. (2021) stated that, water and nitrogen coupling had an impact on transpiration and photosynthetic rate, and stomatal conductance in maize crop.

Yield: Both irrigation and nutrient management strategies had considerable impact over grain and straw yield of rice (Table 3, Fig. 1 and 2). With irrigation method M_2 grain and straw yield of rice was obtained maximum of 4570 and 6166 kg/ha in *kharif* and 4453 and 6013 kg/ha in *rabi* season. This could be owing to effective nutrient uptake under adequate moisture supply which reflected higher accumulation of dry matter thus resulted in higher yield. It was 28.0% higher than M_1 in *kharif* and 28.7% in *rabi*. Scarcity of water and CO_2 hampered photosynthetic process resulted in poor translocation and accumulation of photosynthates which might have reduced both grain and straw yield in treatment M_1 (Arivukkumar *et al*. 2021).

Among nutrient management strategies, S_5 recorded maximum grain and straw yield of about 5048 and 4931 kg/ha in *kharif* and 6797 and 6660 kg/ha in *rabi* and was followed by S_2. Nano N as foliar spray enhances the plant uptake through stomatal penetration, influencing nutrient use efficiency. Nano K as foliar spray might have improved yield traits, boosting grain yield. Similar results were obtained by Velmurugan *et al*. (2021). It was 54% higher than S_7 in *kharif* and 55% in *rabi* while they were observed minimum with S_7.

With regard to interaction, M_2S_5 recorded the maximum grain and straw yield of about 5797 and 7826 kg/ha in *kharif*; 5673 and 7681 kg/ha in *rabi* season. Sufficient water and nutrient supply throughout the crop growth period enhanced the assimilate translocation from source to sink, thus increased the yield attributes, contributed to higher yield. M_1S_7 produced minimum grain and straw yield of 2074 and 2763 kg/ha in *kharif*; and 1957 and 2642 kg/ha in *rabi* season.

Table 2 Effect of water saving irrigation methods and nano NK application on physiological attributes of transplanted rice

Treatment	Transpiration rate (mol/m^2/sec)		Photosynthetic rate (μmol/m^2/sec)		Stomatal conductance (mol/m^2/sec)	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
M						
M_1	4.39	4.29	14.4	13.6	0.24	0.23
M_2	5.19	4.98	19.4	18.1	0.26	0.25
M_3	4.89	4.72	16.5	15.9	0.28	0.27
SEd	0.13	0.12	0.50	0.44	0.007	0.007
CD (P=0.05)	0.28	0.25	1.07	0.95	0.015	0.015
S						
S_1	4.91	4.69	16.8	15.8	0.25	0.24
S_2	4.94	4.79	17.0	16.5	0.27	0.26
S_3	4.82	4.59	16.7	15.8	0.25	0.23
S_4	4.80	4.74	16.8	15.5	0.28	0.27
S_5	4.86	4.77	16.8	15.9	0.27	0.26
S_6	4.79	4.56	16.7	16.0	0.26	0.24
S_7	4.66	4.50	16.6	15.5	0.24	0.20
SEd	0.12	0.11	0.47	0.44	0.006	0.007
CD (P=0.05)	0.26	0.24	1.00	0.94	0.013	0.014
M × S						
M_1S_1	4.42	4.30	14.41	13.42	0.23	0.22
M_1S_2	4.50	4.31	14.52	14.22	0.26	0.24
M_1S_3	4.44	4.31	14.39	13.35	0.24	0.22
M_1S_4	4.41	4.30	14.41	13.39	0.24	0.23
M_1S_5	4.40	4.32	14.49	13.62	0.25	0.25
M_1S_6	4.34	4.28	14.41	14.04	0.24	0.22
M_1S_7	4.25	4.22	14.31	13.32	0.22	0.18
M_2S_1	5.27	4.89	19.54	17.81	0.24	0.23
M_2S_2	5.31	5.26	19.81	18.84	0.26	0.26
M_2S_3	5.09	4.79	19.44	18.43	0.23	0.23
M_2S_4	5.22	5.20	19.46	18.01	0.29	0.28
M_2S_5	5.23	5.21	19.43	18.24	0.28	0.27
M_2S_6	5.19	4.78	19.46	18.32	0.26	0.25
M_2S_7	5.02	4.70	19.35	17.68	0.25	0.20
M_3S_1	5.04	4.87	16.61	16.11	0.28	0.26
M_3S_2	5.00	4.81	16.64	16.42	0.30	0.29
M_3S_3	4.92	4.68	16.51	15.85	0.27	0.25
M_3S_4	4.78	4.71	16.62	15.32	0.31	0.31
M_3S_5	4.96	4.78	16.65	16.09	0.29	0.27
M_3S_6	4.84	4.62	16.43	15.84	0.28	0.26
M_3S_7	4.71	4.59	16.32	15.63	0.25	0.22
SEd	0.13	0.13	0.48	0.45	0.007	0.007
CD (P=0.05)	0.28	0.28	1.02	0.96	0.015	0.014

Treatment details are given under Materials and Methods.

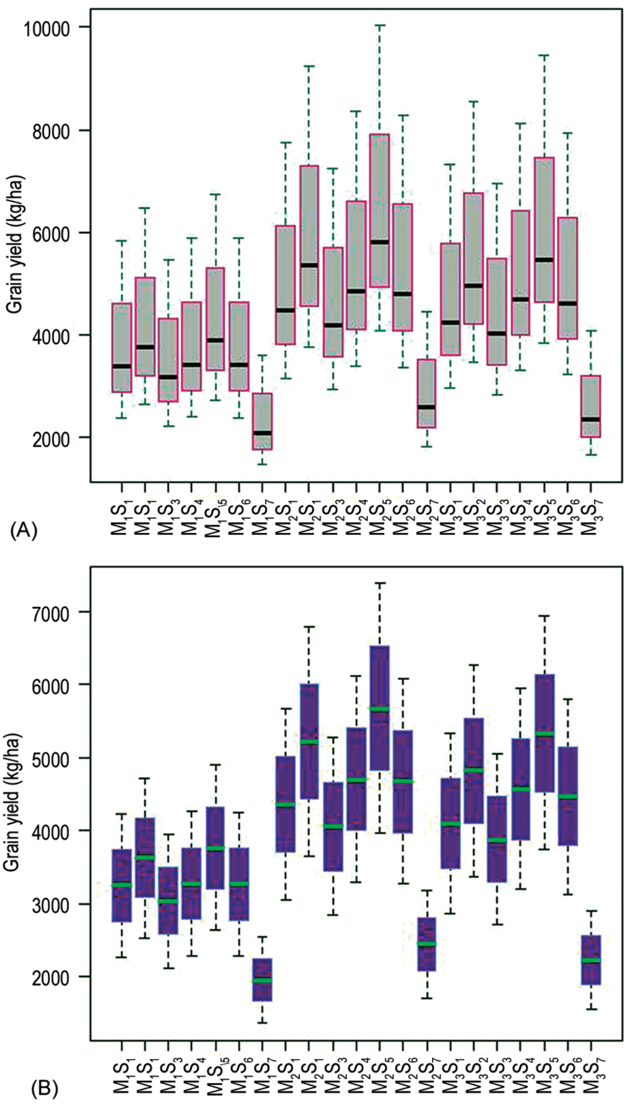

Fig. 1 Effect of irrigation methods and nutrient management strategies on grain yield of transplanted rice during *kharif* (A) and *rabi* (B) seasons.
Treatment details are given under Materials and Methods.

Water use efficiency: Water use efficiency (WUE) was inversely related to total water use. Total water use varied with different irrigation methods and was maximum (1262.6 mm in *kharif* and 1401.9 mm in *rabi*) with treatment M_3 followed by M_2 (1009.6 and 1181.1 mm in both season) and M_1 (913.5 and 1011.3 mm) (Table 3). WUE found maximum under M_2 (4.53 and 3.77 kg/ha/mm) followed by M_1 and minimum with M_3. Application of required amount of irrigation water combined with corresponding yield production might have enhanced WUE. Wang *et al*. (2022) also reported maximum WUE under alternate wetting and drying when compared with severe alternate wetting and drying. With regard to nutrient management practices, S_5 recorded maximum WUE of about 4.77 and 4.12 kg/ha/mm in both the seasons. Sufficient supply of nutrients might have boosted the grain yield. Ahamadian *et al*. (2021) observed higher WUE with application of silica nano-fertilizer in wheat crop.

Table 3 Effect of water saving irrigation methods and nano NK application on yield and WUE of transplanted rice

Treatment	Grain yield (kg/ha)		Straw yield (kg/ha)		WUE (kg/ha/mm)	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
M						
M_1	3290	3169	4385	4283	3.60	3.14
M_2	4570	4448	6166	6013	4.53	3.77
M_3	4325	4200	5813	5680	3.43	3.00
SEd	81.94	80.62	110.50	118.45	0.07	0.06
CD (*P*=0.05)	227.51	223.85	306.82	328.89	0.17	0.13
S						
S_1	4025	3904	5398	5275	3.82	3.28
S_2	4678	4556	6273	6157	4.44	3.82
S_3	3783	3659	5074	4950	3.59	3.08
S_4	4308	4183	5785	5659	4.07	3.50
S_5	5048	4924	6797	6660	4.77	4.12
S_6	4259	4134	5729	5592	4.03	3.46
S_7	2329	2213	3125	2985	2.22	1.87
SEd	117.36	119.21	161.01	158.63	0.07	0.07
CD (*P*=0.05)	238.06	241.79	326.59	321.76	0.16	0.15
M × S						
M_1S_1	3370	3251	4482	4391	3.69	3.22
M_1S_2	3745	3625	4985	4898	4.10	3.59
M_1S_3	3159	3037	4198	4106	3.46	3.01
M_1S_4	3400	3279	4529	4432	3.72	3.25
M_1S_5	3887	3764	5209	5090	4.26	3.73
M_1S_6	3394	3268	4528	4425	3.72	3.24
M_1S_7	2074	1957	2763	2642	2.27	1.94
M_2S_1	4478	4359	6045	5887	4.44	3.69
M_2S_2	5344	5223	7198	7056	5.29	4.43
M_2S_3	4180	4058	5643	5486	4.14	3.44
M_2S_4	4830	4703	6521	6365	4.78	3.99
M_2S_5	5797	5673	7826	7681	5.74	4.81
M_2S_6	4791	4670	6458	6310	4.75	3.96
M_2S_7	2568	2451	3467	3303	2.54	2.08
M_3S_1	4226	4101	5667	5547	3.35	2.93
M_3S_2	4945	4821	6636	6517	3.92	3.44
M_3S_3	4011	3881	5379	5257	3.18	2.78
M_3S_4	4695	4567	6305	6180	3.72	3.27
M_3S_5	5461	5336	7355	7210	4.33	3.81
M_3S_6	4593	4465	6200	6041	3.64	3.19
M_3S_7	2346	2230	3146	3011	1.86	1.59
SEd	205.27	207.47	280.85	280.61	0.13	0.12
CD (*P*=0.05)	440.83	444.25	602.20	606.58	0.29	0.25

Treatment details are given under Materials and Methods. WUE, Water use efficiency.

Regarding interaction, M_2S_5 accounted the maximum WUE of 5.74 and 4.81 kg/ha/mm. Maximum yield coupled with minimum water use promoted higher water use efficiency. Minimum was accounted with conventional flooding with absolute control M_3S_7 in both *kharif* (1.86 kg/ha/mm) and *rabi* (1.59 kg/ha/mm) season respectively. Frequent irrigations accounted for maximum total water use and comparable yield might have declined WUE. Similar result was noted by Ahamadian *et al*. (2021) in which they found that deficit irrigation coupled with application of silica nano fertilizer in wheat registered maximum WUE.

From the experimental findings, it is concluded that adoption of alternate wetting and drying with application of 50% N and K + nano urea and nano potash as foliar spray (M_2S_5) at critical stages increased productivity and input efficiency in transplanted rice.

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