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Effect of Nano Nitrogen and Nano Zinc on Soil Fertility and Crop Productivity of Paddy-paddy Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Field experiments were conducted during *rabi* and *kharif* seasons of 2020-21 and 2021-22 at Krishi Vigyana Kendra, Gangavathi, Koppal, Karnataka, India, to study the influence of nano nitrogen and nano zinc on soil fertility and crop productivity of paddy-paddy cropping system.The experiment

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was laid out in split-split plot design with different levels of nitrogen in main plots, nano nitrogen sprays in sub-plots and nano zinc sprays in sub-sub plots which were replicated thrice. The results of the study indicated that application of 125 per cent RDN along with foliar spray of nitrogen @ 4000 ppm and nano Zn @ 2000 ppm has recorded significantly higher grain yield, straw yield, soil available N, P_2O_5, K_2O, S and Zn during both *rabi* and *kharif* season and which was on par with and 100 per cent RDN along with spray of nano nitrogen @ 4000 ppm and nano Zn @ 2000 ppm. Hence for effective management of nano fertilizers in paddy, the application of 100 per cent RDN along with foliar spray of nano N @ 4000 ppm and foliar spray of nano Zn @ 2000 ppm was recommended.

Keywords: Crop productivity; foliar spray; nano nitrogen; nano zinc; soil fertility.

1. INTRODUCTION

The use of fertilizer is being practiced to produce enough food for increasing population. However, the fertilizers, particularly nitrogen (N) being used in many fold excess due to their low use efficiency and availability in the preferred chemical form, uptake by plants. The typical use efficiency of nitrogen fertilizer (urea) is about 30–40% and phosphate is about 15–20% in most agriculture settings. The unutilized fertilizer input release to the environment and pollute soil, air, water. For instance, urea volatilize in the form of nitrous oxide, a greenhouse gas and emit in the form of ammonia contributing to the global warming and air pollution [1]. The leached urea in form of nitrate through soil affecting the drinking water quality. Moreover, use of urea affects the soil pH that further affects the uptake efficiency of essential macro and micro nutrient by the plants. Soil fertilization with Zn is necessary in Zn-deficient soils because the lack of sufficient Zn early in the crop development may predispose plants to grain yield losses and later fertilization will not alleviate. However the efficiency of applied zinc is around less than 5 per cent, as which there is a need to improve the efficiency of applied Zinc. While, foliar fertilization is an effective way of increasing Zn concentration in the grain as Zn is relatively easily transported in the phloem. To improve the nutrient use efficiency, alternative smart Agri-inputs based on the concepts of advanced chemical engineering, biotechnology, microbiology, polymer science are being developed for the control and slow release of nutrient in the soil [2]. However, success is limited due to varying agro-climatic conditions, plant and food demand diversity and soil nutrient profiles. World population is expected to grow over 10 billion by 2100 and Asia is the top continent by population, hence the food demand is more. Therefore, it is important to develop and adopt sustainable practices wherein adequate food can be produced while minimizing the environmental impact of less efficient fertilizers.

Since last two decades, nanotechnology is being explored to enhance the nutrient use efficiency and target delivery of nutrients to plants. Fertilizers made at nanoscale (1–100 nm) having higher surface area to volume size ratio and feature of surface functionalization along with slow or plant response based release [3]. For instance, zinc oxide nano fertilizers were used to mobilize native phosphorus in soil in addition to fertilize the zinc itself. Similarly, urea coated with hydroxyapatite was tested on rice crop with the aim to reduce the bulk use of alternative nitrogen [4]. The interesting observation evidenced from the laboratory or small scale field trials of nanotechnology based fertilizer inputs was the reduction in the demand of conventional bulk alternatives while maintaining or increasing the crop productivity. This inspires the present study to investigate the influence of nano fertilizers of nitrogen and zinc along with different levels of conventional nitrogen fertilizer is being practiced. The nano fertilizers were used to reduce the imbalanced use of bulk fertilizer such as urea with a larger aim to demonstrate alternative practice for sustainable and precision agriculture.

2. MATERIALS AND METHODS

The field experiments were conducted in Krishi Vigyana Kendra, Gangavathi (Dist: Koppal) during *rabi* season of 2020-2021 and *kharif and rabi* season of2021-2022. The experiment sitesituated in the Northern Dry Zone (Zone 3) of Karnataka state lying between 15° 15′ 40″ North (latitude) and 76° 31′ 40″ East (longitude) with an altitude of 419 m above mean sea level. The soil of the experimental site was clay in texture with saline pH (8.03), medium EC (1.26dS m^{-1}) and high in OC (7.01 g kg^{-1}). The soil was low in available nitrogen (191.25kg ha^{-1}), high in available phosphorus (51.67 kg ha^{-1}) & medium in available potassium (302.77 kg ha^{-1}) and available sulphur (18.31 mg kg^{-1}). The DTPA extractable Zn, Fe, Mn and Cu were in sufficient range with values 1.05, 5.51, 5.34 and 3.73 mg kg^{-1}, respectively. The variety used in the study was RNR 15048 (TelenganaSona) and it can be cultivated during both *kharif* and *rabi* season.

During the growing seasons, treatments of different levels of nitrogen (M), nano nitrogen (N) and nano zinc (Z) were carried out in a split-split plot design with the main plot of factor M, 4 levels, sub factor of N, 3 levels and sub factor of Z, 2 levels (Table 1). Recommended dose of P & K were applied through conventional fertilizer and FYM was common for all the treatments except absolute control. Absolute control (water spray) was maintained separately outside the layout of the experiment for comparison. Nano nitrogen and nano zinc contains 4 % N and 1 % Zn, respectively.

2.1 Analysis of Soil Properties

Representative soil samples from each experimental plot were drawn from the top 0-15 cm at panicle initiation (PI) and harvest stage (HS) of paddy crop in each season. Soil samples thus collected were air dried in shade, powdered and passed through 2 mm sieve and analysed for available nutrient status [N, P, K, S and micronutrients (Zn , Fe, Mn& Cu)].

2.2 Yield Measurement

Each season, the above ground biomass of all plants was manually harvested separately from the net plot, threshed and dried in sun. The grains were cleaned and weight was recorded in kg per hectare (kg ha^{-1}).

2.3 Statistical Analysis

The experimental data were subjected to statistical scrutiny to find out the influence of treatments on growth, yield and nutrient uptake by paddy. Further the effects were tested at 5% level of significance [5].

3. RESULTS AND DISCUSSION

There was a slight difference in crop yield, soil available P_2O_5, K_2O, S and micronutrients (Zn. Fe, Cu and Mn) during both *kharif* and *rabi* experiments, but the pattern of response were similar. Hence, only pooled data of the *rabi* season and one year data of *kharif* season are used to emphasize the results.

3.1 Productivity of Paddy-paddy Cropping System (Table 2)

Grain and straw yield differed significantly between different levels of nitrogen and foliar spray of nano N. Among the different levels of nitrogen, addition of 125 per cent RDN (M_4) registered higher grain and straw yield of 5659 & 5405 kg ha^{-1} and 6836 and 6595 kg ha^{-1} which wason par with 100 per cent RDN with $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} (M_1: 5485 & 5217 kg ha^{-1} and 6690 & 6417 kg ha^{-1}) and 100 per cent RDN (M_3:5375 & 5113 kg ha^{-1} and 6557 and 6290 kg ha^{-1}). While, lower grain and straw yield was noticed with 75 per cent RDN (M_2: 5206 &4942 kg ha^{-1} and 6353 and 6129 kg ha^{-1}) during *rabi* and *kharif* season, respectively (Table 4). Irrespective of foliar spray of nano N, significantly higher grain and straw yield was observed in treatment with foliar spray of nano N @ 4000 ppm (N_2: 5623 & 5352 kg ha^{-1} and 6840 and 6581kg ha^{-1}) followed by foliar spray of nano N @ 2000 ppm (N_1: 5359 & 5101 kg ha^{-1} and 6522 and 6273 kg ha^{-1}) and foliar spray of nano N @ 6000 ppm (N_3: 5312 &5056 kg ha^{-1} and 6465 and 6218 kg ha^{-1}) during *rabi* and *kharif* season, respectively. While, no significant difference was observed in foliar spray of nano Zn, however, higher grain and straw yield (5479 & 5215 kg ha^{-1} and 6667 and 6413 kg ha^{-1}) was noticed in nano Zn @ 2000 ppm (Z_1) and was on par with the Z_2 (foliar spray of nano N @ 3000 ppm: 5384 & 5124 kg ha^{-1} and 6551 & 6302 kg ha^{-1}during *rabi* and *kharif* season, respectively). While, lower grain and straw yield of 3688 & 3668 kg ha^{-1} and 4588 and 4569 kg ha^{-1} was registered in absolute control, during *rabi* and *kharif* season, respectively.

Grain and straw yield increases with the increasing level of N from 100 to 150 per cent RDN was reported by Bhowmick and Nayak [6]. Higher grain and straw yield at M_4 may be ascribed to the overall improvement in plant vigour and production of sufficient photosynthates owing to greater availability of nutrients subsequently resulting in better manifestation of yield attributes [7]. The increase in grain and straw yield due to combined application of nano particles of nano N as foliar at 4000 ppm at tillering and panicle initiation and foliar spray of nano Zn at 2000 ppm at tillering stage is mainly attributed to higher grain and straw yield components and also stimulation

Table 1. Treatment details

Main plot: Soil nitrogen management (M)	Subplot: Foliar spray (FS) of nano nitrogen (N)	Subplot: Foliar spray (FS) of nanozinc (Z)
M_1: 100 % RDF ($ZnSO_4.7H_2O$ @ 25 kg ha^{-1}) **M_2**: 75 % RDN **M_3**: 100 % RDN **M_4**: 125 % RDN	**N_1**:FS of nano N @ 2000 ppm (2 ml L^{-1}) **N_2**: FS of nano N @ 4000 ppm (4 ml L^{-1}) **N_3**: FS of nano N @ 6000 ppm (6 ml L^{-1})	**Z_1**:FS of nanoZn @ 2000 ppm (2 ml L^{-1}) **Z_2**:FS of nanoZn @ 3000 ppm (3 ml L^{-1})

effect of zinc which helps in increasing enzymatic activity. Muthukumararaja & Srirama Chandra sekharan [8] reported that grain and straw yield of rice increase is due to enhanced synthesis of carbohydrate and their transport to the site of grain production.

3.2 Soil Fertility

Among different nitrogen levels (Tables 3 to 7), 125 per cent RDN (M_4) recorded higher soil available nitrogen (M_4: 241.65 & 222.40 and 262.38 & 233.23 kg ha^{-1}), P_2O_5 (58.00 & 42.69 and 61.05 & 49.16 kg ha^{-1}),K_2O (366.33 & 326.68 and 370.90 & 331.90 kg ha^{-1}) and S (21.38 & 16.97 and 21.87 & 17.81 mg kg^{-1}), however, higher DTPA-Zn recorded with 100 per cent RDN with $ZnSO_4.7H_2O$ at 25 kg ha^{-1} (1.20 & 1.11 and 1.26 & 1.17 mg kg^{-1}) at panicle initiation (PI) and harvest stage (HS) of paddy crop (82.09 & 97.11 and 78.51 & 96.54 cm during *rabi* and *kharif* season, respectively) as compared to other treatments of different nitrogen levels (Table 2). Similarly, significant higher soil available nitrogen was recorded by foliar spray of nano N @ 4000 ppm (N_2: 225.61 & 206.36 and 242.82 & 212.57 kg ha^{-1}),P_2O_5 (56.74 & 41.23 and 59.36 & 47.56 kg ha^{-1}), K_2O (354.20 & 314.55 and 358.77m& 319.77 kg ha^{-1}), S (19.34 & 15.94 and 20.24 & 15.74 mg kg^{-1}) and Zn (1.16 & 1.07 and 1.22 & 1.13 mg kg^{-1}) at panicle initiation (PI)&harvest stage (HS)of paddy crop during *rabi* and *kharif* season, respectively, followed by FS of nano N @ 2000 ppm (N_1) and 6000 ppm (N_3).The treatment, foliar spray of nano Zn @ 2000 ppm (Z_1: 157.44 and 141.44 kg ha^{-1}) recorded maximum soil available N, P_2O_5, K_2O, S and Zn, but non-significant and was on par with the foliar spray of nano Zn @ 3000 ppm during *rabi* and *kharif* season, respectively. Whereas, minimum soil available N, P_2O_5, K_2O, S and Zn was recorded in absolute control.

As far as the interaction effect, it is evident from the data that total N uptake by paddy showed non-significant difference but the higher soil available N (246.90 & 227.65 and 274.78 & 244.24 kg ha^{-1}), P_2O_5 (55.41 & 40.20 and 58.31 & 46.56 kg ha^{-1}), K_2O (344.22, &304.57 and 348.80 & 309.80 kg ha^{-1}), S (18.85 & 15.46 and 19.70 & 15.37 mg kg^{-1}) and Zn (1.25 & 1.16 and 1.31 & 1.22 mg kg^{-1}) was recorded with the combination of 125 per cent RDN along with FS of nano N @ 4000 ppm and nano Zn @ 2000 ppm. While, lower soil available N (188.55 & 169.30 and 195.74 & 162.03 kg ha^{-1}), P_2O_5 (49.37 & 34.73 and 52.14, & 40.72 kg ha^{-1}), K_2O (304.66 & 265.01 and 309.24 & 270.24 kg ha^{-1}) and S (15.01 & 12.54 and 16.31 & 11.74 mg kg^{-1}) during *rabi* and *kharif* season, respectively, was recorded with the combination of 75 per cent RDN along with FS of nano N @ 6000 ppm and nano Zn @ 3000 ppm.

Soil available N, P_2O_5, K_2O, S and Zn showed decreasing trend from panicle initiation stage to harvest stage of paddy under different levels of soil N, FS nano N and FS nano Zn studied which may be attributed to the continuous absorption of P_2O_5, K_2O, S and Zn by crop with increasing biomass as the crop growth stage advances. The significant increase in available N content might be due to synergistic interaction between zinc and nitrogen. This increase in available N was due to fertilizer application to treatment plots. Similar results were obtained by Ramrao [9] in paddy by application of nano Zn.Potassium use efficiency was increased in wheat crop by integrated use of nano and non-nano fertilizers *i.e*., nano 100 % NPK + Nano NPK sprays at 20, 30 and 45 DAS @ 3 ml $litre^{-1}$ of water + 2 Nano-K sprays at grain development stage @ 4 ml $litre^{-1}$ of water 115 and 125 DAS, Swati and Rajeev [10]. Application of nano nitrogen chelated fertilizer (NNC) had significant effect on reducing nitrate leaching and increasing sugar production in sugarcane and NUE [11]. Application of nano N and Zn increased the availability of sulphur in the soil. This may be due to synergistic effect of nitrogen and zinc on sulphur which might have enhanced the availability of sulphur for the plant growth. These results corroborate with the findings of Singh and Kumar [12] in sunflower by foliar spray of 500 ppm nano ZnS.

Table 2. Grain yield and straw yield of paddy as influenced by different levels of nitrogen with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		Grain yield (kg ha^{-1})								Straw yield (kg ha^{-1})							
		Rabi (Pooled 2021 and 2022)				*Kharif* -2021				*Rabi* (Pooled 2021 and 2022)				*Kharif* -2021			
		N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ
M_1	Z_1	5480	5743	5377	**5533**	5213	5463	5115	**5264**	6684	7003	6559	**6749**	6412	6720	6292	**6474**
	Z_2	5352	5604	5352	**5436**	5091	5331	5091	**5171**	6529	6834	6528	**6630**	6262	6557	6262	**6360**
M_2	Z_1	5246	5380	5137	**5254**	4979	5107	4877	**4988**	6400	6563	6269	**6411**	6175	6333	6047	**6185**
	Z_2	5191	5234	5051	**5159**	4927	4969	4794	**4897**	6334	6386	6164	**6295**	6110	6161	5945	**6072**
M_3	Z_1	5375	5716	5188	**5426**	5113	5437	4935	**5162**	6557	6969	6330	**6619**	6290	6688	6070	**6349**
	Z_2	5234	5622	5118	**5325**	4979	5348	4868	**5065**	6386	6856	6245	**6496**	6124	6578	5988	**6230**
M_4	Z_1	5580	5856	5670	**5702**	5330	5594	5416	**5447**	6742	7074	6850	**6889**	6503	6824	6608	**6645**
	Z_2	5417	5825	5604	**5615**	5174	5564	5353	**5364**	6544	7037	6770	**6784**	6312	6789	6531	**6544**
N		**5359**	**5623**	**5312**		**5101**	**5352**	**5056**		**6522**	**6840**	**6465**		**6273**	**6581**	**6218**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	M_1	5416	5674	5364	**5485**	5152	5397	5103	**5217**	6606	6918	6544	**6690**	6337	6638	6277	**6417**
	M_2	5218	5307	5094	**5206**	4953	5038	4836	**4942**	6367	6475	6217	**6353**	6142	6247	5996	**6129**
	M_3	5305	5669	5153	**5375**	5046	5393	4901	**5113**	6472	6913	6288	**6557**	6207	6633	6029	**6290**
	M_4	5499	5841	5637	**5659**	5252	5579	5385	**5405**	6643	7056	6810	**6836**	6408	6807	6569	**6595**
		NxZ			**Z**	**NxZ**			**Z**	**NxZ**			**Z**	**NxZ**			**Z**
Z	Z_1	5420	5674	5343	**5479**	5159	5400	5086	**5215**	6596	6902	6502	**6667**	6345	6641	6254	**6413**
	Z_2	5298	5571	5281	**5384**	5043	5303	5027	**5124**	6448	6778	6427	**6551**	6202	6521	6181	**6302**
Control		**3688**				**3668**				**4588**				**4569**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**	**CD at 5 %**		
M		81.53		293.53		82.89		295.35		90.08		311.72		91.25	320.83		
N		58.37		175.00		55.82		167.36		82.76		248.11		68.65	205.83		
Z		51.43		NS		52.28		NS		61.71		NS		63.46	NS		
M x N		116.75		NS		111.65		NS		165.51		NS		137.31	NS		
M x Z		102.86		NS		104.56		NS		123.42		NS		126.92	NS		
N x Z		89.08		NS		90.55		NS		106.88		NS		109.92	NS		
M x N x Z		178.16		NS		181.11		NS		213.77		NS		219.83	NS		
Control vs Rest		262.82		454.74		164.95		285.40		330.98		572.66		192.00	332.20		

NOTE:
NS : Non significant
Main plot : Soil nitrogen management (M) — *M_1 : 100 % RDF + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1}* — *M_2 : 75 % RDN* — *M_3 : 100 % RDN* — *M_4 : 125 % RDN*
Sub plot : Foliar spray of nano nitrogen (N) — *N_1 : FS of nano N @ 2000 ppm* — *N_2 : FS of nano N @ 4000 ppm* — *N_3 : FS of nano N @ 6000 ppm*
Sub-sub plot : Foliar spray of nano zinc (Z) — *Z_1 : FS of nano Zn @ 2000 ppm* — *Z_2 : FS of nano Zn @ 3000 ppm*

Table 3. Soil available nitrogen (kg ha^{-1}) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		**Panicle initiation**								**At harvest**							
		***Rabi* (Pooled 2021 and 2022)**				***Kharif* -2021**				***Rabi* (Pooled 2021 and 20222)**				***Kharif* -2021**			
		N_1	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**
M_1	**Z_1**	224.60	230.32	222.17	**225.69**	240.12	248.77	226.92	**238.61**	205.35	211.07	202.92	**206.44**	213.44	221.13	201.71	**212.09**
	Z_2	221.88	227.63	221.26	**223.59**	234.48	241.68	223.61	**233.26**	202.63	208.38	202.01	**204.34**	208.43	214.83	198.77	**207.34**
M_2	**Z_1**	197.18	200.10	191.63	**196.30**	209.99	220.11	199.68	**209.93**	177.93	180.85	172.38	**177.05**	173.83	182.20	165.29	**173.77**
	Z_2	195.74	198.46	188.55	**194.25**	202.94	208.53	195.74	**202.40**	176.49	179.21	169.30	**175.00**	167.99	172.62	162.03	**167.55**
M_3	**Z_1**	222.79	229.41	217.01	**223.07**	233.89	241.63	220.56	**232.03**	203.54	210.16	197.76	**203.82**	207.90	214.78	196.05	**206.25**
	Z_2	217.92	227.41	214.99	**220.11**	226.53	240.40	218.75	**228.56**	198.67	208.16	195.74	**200.86**	201.36	213.69	194.45	**203.16**
M_4	**Z_1**	242.67	246.90	239.41	**242.99**	263.64	274.78	256.81	**265.08**	223.42	227.65	220.16	**223.74**	234.35	244.24	228.27	**235.62**
	Z_2	240.53	244.66	235.73	**240.31**	261.71	266.66	250.71	**259.69**	221.28	225.41	216.48	**221.06**	232.63	237.04	222.85	**230.84**
N		**220.41**	**225.61**	**216.34**		**234.16**	**242.82**	**224.10**		**201.16**	**206.36**	**197.09**		**204.99**	**212.57**	**196.18**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	**M_1**	223.24	228.98	221.71	**224.64**	237.30	245.23	225.27	**235.93**	203.99	209.73	202.46	**205.39**	210.94	217.98	200.24	**209.72**
	M_2	196.46	199.28	190.09	**195.28**	206.47	214.32	197.71	**206.17**	177.21	180.03	170.84	**176.03**	170.91	177.41	163.66	**170.66**
	M_3	220.35	228.41	216.00	**221.59**	230.21	241.01	219.66	**230.29**	201.10	209.16	196.75	**202.34**	204.63	214.23	195.25	**204.70**
	M_4	241.60	245.78	237.57	**241.65**	262.68	270.72	253.76	**262.38**	222.35	226.53	218.32	**222.40**	233.49	240.64	225.56	**233.23**
		NxZ			**Z**	**NxZ**			**Z**	**NxZ**			**Z**	**NxZ**			**Z**
Z	**Z_1**	221.81	226.68	217.55	**222.02**	236.91	246.32	225.99	**236.41**	202.56	207.43	198.30	**202.77**	207.38	215.59	197.83	**206.93**
	Z_2	219.02	224.54	215.13	**219.56**	231.42	239.32	222.20	**230.98**	199.77	205.29	195.88	**200.31**	202.60	209.54	194.52	**202.22**
Control		**98.75**				**98.75**				**74.04**				**65.59**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**	**CD at 5 %**		
M (MP)		2.66		9.20		3.27		11.33		2.26		7.82		3.05	10.57		
N (SP)		1.89		4.68		2.11		6.33		1.94		4.82		2.01	6.01		
Z (SSP)		2.33		NS		2.60		NS		1.89		NS		2.14	NS		
M x N		3.79		NS		4.22		NS		3.88		NS		4.01	NS		
M x Z		4.67		NS		5.19		NS		3.78		NS		4.29	NS		
N x Z		4.04		NS		4.50		NS		3.27		NS		3.71	NS		
M x N x Z		8.09		NS		8.99		NS		6.55		NS		7.43	NS		
Control vs Rest		9.77		16.91		12.03		20.82		8.31		14.37		11.22	19.42		

NOTE:
NS : Non significant
Main plot : Soil nitrogen management (M) M_1 : 100 % RDF + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} M_2 : 75 % RDN M_3 : 100 % RDN M_4 : 125 % RDN
Sub plot : Foliar spray of nano nitrogen (N) N_1 : FS of nano N @ 2000 ppm N_2 : FS of nano N @ 4000 ppm N_3 : FS of nano N @ 6000 ppm
Sub-sub plot : Foliar spray of nano zinc (Z) Z_1 : FS of nano Zn @ 2000 ppm Z_2 : FS of nano Zn @ 3000 ppm

Table 4. Soil available phosphorus (kg ha^{-1}) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		Panicle initiation								At harvest							
		Rabi (Pooled 2021 and 2022)				*Kharif* -2021				*Rabi* (Pooled 2021 and 20222)				*Kharif* -2021			
		N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ
M_1	Z_1	55.14	57.45	53.62	**55.41**	58.19	60.24	57.00	**58.48**	40.47	42.06	39.07	**40.53**	46.58	48.04	45.74	**46.79**
	Z_2	54.36	55.94	52.79	**54.36**	57.33	58.83	56.41	**57.52**	39.61	40.86	38.41	**39.63**	45.97	47.04	45.11	**46.04**
M_2	Z_1	52.36	54.98	50.50	**52.61**	54.43	56.76	53.19	**54.79**	37.26	39.27	35.58	**37.37**	43.35	45.21	41.56	**43.37**
	Z_2	50.97	52.76	49.37	**51.03**	53.51	55.38	52.14	**53.68**	36.15	37.49	34.73	**36.12**	42.62	44.11	40.72	**42.48**
M_3	Z_1	55.26	57.31	52.87	**55.15**	58.91	60.01	56.05	**58.33**	40.28	41.45	37.52	**39.75**	47.43	48.22	43.93	**46.53**
	Z_2	54.19	55.78	51.83	**53.93**	57.21	57.34	55.51	**56.69**	37.85	40.37	36.78	**38.33**	44.04	46.30	42.81	**44.38**
M_4	Z_1	58.27	60.56	56.60	**58.48**	61.40	63.76	59.78	**61.65**	42.92	44.75	41.76	**43.14**	49.62	51.17	47.89	**49.56**
	Z_2	57.71	59.13	55.75	**57.53**	60.66	62.54	58.12	**60.44**	42.49	43.58	40.63	**42.23**	49.13	50.36	46.79	**48.76**
N		**54.78**	**56.74**	**52.92**		**57.71**	**59.36**	**56.03**		**39.63**	**41.23**	**38.06**		**46.09**	**47.56**	**44.32**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	M_1	54.75	56.70	53.21	**54.88**	57.76	59.54	56.70	**58.00**	40.04	41.46	38.74	**40.08**	46.28	47.54	45.43	**46.41**
	M_2	51.66	53.87	49.93	**51.82**	53.97	56.07	52.66	**54.24**	36.70	38.38	35.15	**36.75**	42.98	44.66	41.14	**42.93**
	M_3	54.72	56.54	52.35	**54.54**	58.06	58.68	55.78	**57.51**	39.06	40.91	37.15	**39.04**	45.74	47.26	43.37	**45.46**
	M_4	57.99	59.84	56.18	**58.00**	61.03	63.15	58.95	**61.05**	42.71	44.16	41.19	**42.69**	49.37	50.77	47.34	**49.16**
		NxZ			**Z**	**NxZ**			**Z**	**NxZ**			**Z**	**NxZ**			**Z**
Z	Z_1	55.26	57.57	53.40	**55.41**	58.23	60.19	56.51	**58.31**	40.23	41.88	38.48	**40.20**	46.74	48.16	44.78	**46.56**
	Z_2	54.31	55.90	52.44	**54.21**	57.18	58.53	55.54	**57.08**	39.02	40.57	37.64	**39.08**	45.44	46.95	43.86	**45.42**
Control		**27.23**				**27.94**				**21.02**				**21.34**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**	**CD at 5 %**		
M (MP)		0.41		1.41		0.57		1.98		0.28		0.96		0.73	2.51		
N (SP)		0.45		1.33		0.31		0.94		0.38		1.13		0.52	1.45		
Z (SSP)		0.50		NS		0.56		NS		0.32		NS		0.43	NS		
M x N		0.89		NS		0.63		NS		0.76		NS		1.03	NS		
M x Z		1.00		NS		1.11		NS		0.64		NS		0.86	NS		
N x Z		0.86		NS		0.96		NS		0.55		NS		0.75	NS		
M x N x Z		1.73		NS		1.93		NS		1.11		NS		1.50	NS		
Control vs Rest		1.49		2.58		2.10		3.63		1.02		1.77		2.67	4.61		

NOTE:
NS : Non significant
Main plot : Soil nitrogen management (M) M_1 : 100 % RDF + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1} M_2 : 75 % RDN M_3 : 100 % RDN M_4 : 125 % RDN
Sub plot : Foliar spray of nano nitrogen (N) N_1 : FS of nano N @ 2000 ppm N_2 : FS of nano N @ 4000 ppm N_3 : FS of nano N @ 6000 ppm
Sub-sub plot : Foliar spray of nano zinc (Z) Z_1 : FS of nano Zn @ 2000 ppm Z_2 : FS of nano Zn @ 3000 ppm

Table 5. Soil available potassium (kg ha^{-1}) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		Panicle initiation								At harvest							
		Rabi (Pooled 2021 and 2022)				*Kharif* -2021				*Rabi* (Pooled 2021 and 20222)				*Kharif* -2021			
		N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ
M_1	Z_1	345.90	359.35	325.36	**343.54**	350.48	363.93	329.94	**348.11**	306.25	319.70	285.71	**303.89**	311.48	324.93	290.94	**309.11**
	Z_2	337.13	348.32	320.22	**335.22**	341.70	352.90	324.79	**339.80**	297.48	308.67	280.57	**295.57**	302.70	313.90	285.79	**300.80**
M_2	Z_1	326.83	342.57	310.79	**326.73**	331.40	347.15	315.37	**331.31**	287.18	302.92	271.14	**287.08**	292.40	308.15	276.37	**292.31**
	Z_2	315.86	324.56	304.66	**315.03**	320.43	329.13	309.24	**319.60**	276.21	284.91	265.01	**275.38**	281.43	290.13	270.24	**280.60**
M_3	Z_1	339.00	351.04	318.27	**336.10**	343.58	355.62	322.85	**340.68**	299.35	311.39	278.62	**296.45**	304.58	316.62	283.85	**301.68**
	Z_2	327.55	349.13	315.45	**330.71**	332.13	353.71	320.03	**335.29**	287.90	309.48	275.80	**291.06**	293.13	314.71	281.03	**296.29**
M_4	Z_1	368.29	385.60	357.65	**370.51**	372.86	390.18	362.22	**375.09**	328.64	345.95	318.00	**330.86**	333.86	351.18	323.22	**336.09**
	Z_2	365.28	372.99	348.16	**362.14**	369.86	377.56	352.74	**366.72**	325.63	333.34	308.51	**322.49**	330.86	338.56	313.74	**327.72**
N		**340.73**	**354.20**	**325.07**		**345.30**	**358.77**	**329.65**		**301.08**	**314.55**	**285.42**		**306.30**	**319.77**	**290.65**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	M_1	341.51	353.84	322.79	**339.38**	346.09	358.41	327.37	**343.96**	301.86	314.19	283.14	**299.73**	307.09	319.41	288.37	**304.96**
	M_2	321.34	333.56	307.73	**320.88**	325.92	338.14	312.30	**325.45**	281.69	293.91	268.08	**281.23**	286.92	299.14	273.30	**286.45**
	M_3	333.28	350.09	316.86	**333.41**	337.85	354.66	321.44	**337.98**	293.63	310.44	277.21	**293.76**	298.85	315.66	282.44	**298.98**
	M_4	366.79	379.30	352.91	**366.33**	371.36	383.87	357.48	**370.90**	327.14	339.65	313.26	**326.68**	332.36	344.87	318.48	**331.90**
		NxZ			**Z**	**NxZ**			**Z**	**NxZ**			**Z**	**NxZ**			**Z**
Z	Z_1	345.00	359.64	328.02	**344.22**	349.58	364.22	332.59	**348.80**	305.35	319.99	288.37	**304.57**	310.58	325.22	293.59	**309.80**
	Z_2	336.45	348.75	322.12	**335.78**	341.03	353.32	326.70	**340.35**	296.80	309.10	282.47	**296.13**	302.03	314.32	287.70	**301.35**
Control		**208.37**				**208.16**				**188.60**				**187.64**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**	
M (MP)		4.12		14.26		4.38		15.16		3.29		11.40		5.01		17.33	
N (SP)		3.98		11.93		3.50		10.49		2.34		7.01		3.20		9.59	
Z (SSP)		3.04		NS		3.86		NS		3.40		NS		2.99		NS	
M x N		7.96		NS		7.00		NS		4.67		NS		6.40		NS	
M x Z		6.08		NS		7.72		NS		6.80		NS		5.98		NS	
N x Z		5.26		NS		6.68		NS		5.89		NS		5.18		NS	
M x N x Z		10.52		NS		13.37		NS		11.77		NS		10.35		NS	
Control vs Rest		15.14		26.20		16.09		27.84		12.10		20.94		18.40		31.83	

NOTE:
NS : Non significant
Main plot : Soil nitrogen management (M)   *M_1 : 100 % RDF + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1}*   *M_2 : 75 % RDN*   *M_3 : 100 % RDN*   *M_4 : 125 % RDN*
Sub plot : Foliar spray of nano nitrogen (N)   *N_1 : FS of nano N @ 2000 ppm*   *N_2 : FS of nano N @ 4000 ppm*   *N_3 : FS of nano N @ 6000 ppm*
Sub-sub plot : Foliar spray of nano zinc (Z)   *Z_1 : FS of nano Zn @ 2000 ppm*   *Z_2 : FS of nano Zn @ 3000 ppm*

Table 6. Soil available sulphur (kg ha^{-1}) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		Panicle initiation								At harvest							
		Rabi (Pooled 2021 and 2022)				*Kharif* -2021				*Rabi* (Pooled 2021 and 20222)				*Kharif* -2021			
		N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ	N_1	N_2	N_3	MxZ
M_1	Z_1	19.14	19.84	18.40	**19.13**	20.01	20.73	18.91	**19.88**	16.02	16.61	15.42	**16.02**	15.59	16.17	15.26	**15.67**
	Z_2	18.77	19.31	18.12	**18.73**	19.54	20.14	18.63	**19.44**	15.71	16.17	15.18	**15.69**	15.35	15.77	15.01	**15.38**
M_2	Z_1	16.15	16.73	15.35	**16.08**	17.50	18.34	16.64	**17.49**	13.49	13.97	12.83	**13.43**	12.66	12.95	12.04	**12.55**
	Z_2	15.71	16.25	15.01	**15.66**	16.91	17.38	16.31	**16.87**	13.13	13.59	12.54	**13.09**	12.41	12.93	11.74	**12.36**
M_3	Z_1	18.91	19.41	17.55	**18.62**	19.49	20.14	18.38	**19.34**	15.84	16.26	13.67	**15.26**	15.63	15.94	14.27	**15.28**
	Z_2	17.81	18.90	17.21	**17.98**	18.88	20.03	18.23	**19.05**	14.90	15.82	13.41	**14.71**	14.31	15.19	13.83	**14.44**
M_4	Z_1	21.55	22.40	20.83	**21.59**	21.97	22.90	21.40	**22.09**	17.10	17.78	16.53	**17.14**	18.01	18.67	17.27	**17.98**
	Z_2	21.35	21.87	20.30	**21.17**	21.81	22.22	20.89	**21.64**	16.94	17.35	16.11	**16.80**	17.80	18.32	16.81	**17.64**
N		**18.67**	**19.34**	**17.85**		**19.51**	**20.24**	**18.67**		**15.39**	**15.94**	**14.46**		**15.22**	**15.74**	**14.53**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	M_1	18.95	19.57	18.26	**18.93**	19.78	20.44	18.77	**19.66**	15.87	16.39	15.30	**15.85**	15.47	15.97	15.13	**15.53**
	M_2	15.93	16.49	15.18	**15.87**	17.21	17.86	16.48	**17.18**	13.31	13.78	12.69	**13.26**	12.54	12.94	11.89	**12.46**
	M_3	18.36	19.16	17.38	**18.30**	19.18	20.08	18.30	**19.19**	15.37	16.04	13.54	**14.98**	14.97	15.56	14.05	**14.86**
	M_4	21.45	22.13	20.57	**21.38**	21.89	22.56	21.15	**21.87**	17.02	17.57	16.32	**16.97**	17.90	18.49	17.04	**17.81**
		NxZ			**Z**	**NxZ**		**Z**		**NxZ**			**Z**	**NxZ**			**Z**
Z	Z_1	18.94	19.59	18.03	**18.85**	19.74	20.53	18.83	**19.70**	15.62	16.15	14.61	**15.46**	15.47	15.93	14.71	**15.37**
	Z_2	18.41	19.08	17.66	**18.38**	19.28	19.94	18.52	**19.25**	15.17	15.73	14.31	**15.07**	14.97	15.55	14.35	**14.96**
Control		**10.59**				**10.61**				**8.50**				**9.02**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**	
M (MP)		0.20		0.69		0.18		0.61		0.14		0.48		0.20		0.68	
N (SP)		0.19		0.57		0.21		0.63		0.16		0.48		0.18		0.44	
Z (SSP)		0.18		NS		0.20		NS		0.16		NS		0.15		NS	
M x N		0.38		NS		0.42		NS		0.32		NS		0.36		NS	
M x Z		0.37		NS		0.39		NS		0.31		NS		0.31		NS	
N x Z		0.32		NS		0.34		NS		0.27		NS		0.26		NS	
M x N x Z		0.64		NS		0.68		NS		0.54		NS		0.53		NS	
Control vs Rest		0.74		1.27		0.64		1.12		0.51		0.88		0.73		1.26	

NOTE:
NS : Non significant

Main plot	:	*Soil nitrogen management (M)*	M_1	:	*100 % RDF +* $ZnSO_4.7H_2O$ *@ 25 kg ha*$^{-1}$	M_2	:	*75 % RDN*	M_3	:	*100 % RDN* M_4 *: 125 % RDN*
Sub plot	:	*Foliar spray of nano nitrogen (N)*	N_1	:	*FS of nano N @ 2000 ppm*	N_2	:	*FS of nano N @ 4000 ppm*	N_3	:	*FS of nano N @ 6000 ppm*
Sub-sub plot	:	*Foliar spray of nano zinc (Z)*	Z_1	:	*FS of nano Zn @ 2000 ppm*	Z_2	:	*FS of nano Zn @ 3000 ppm*			

Table 7. Soil DTPA-Zn (mg kg^{-1}) at flowering and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi* (pooled 2021 and 2022) and *kharif* (2021)

MxNxZ		Panicle initiation								At harvest							
		Rabi (Pooled 2021 and 2022)				*Kharif* -2021				*Rabi* (Pooled 2021 and 20222)				*Kharif*-2021			
		N_1	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**	**N_1**	**N_2**	**N_3**	**MxZ**
M_1	**Z_1**	1.19	1.25	1.20	**1.21**	1.25	1.31	1.26	**1.27**	1.10	1.16	1.11	**1.12**	1.16	1.22	1.17	**1.18**
	Z_2	1.15	1.24	1.19	**1.19**	1.21	1.30	1.25	**1.25**	1.06	1.15	1.10	**1.10**	1.12	1.21	1.16	**1.16**
M_2	**Z_1**	1.05	1.08	1.03	**1.05**	1.11	1.14	1.09	**1.11**	0.95	0.98	0.93	**0.95**	1.01	1.04	0.99	**1.01**
	Z_2	1.04	1.05	1.01	**1.03**	1.10	1.11	1.07	**1.09**	0.94	0.95	0.91	**0.93**	1.00	1.01	0.97	**0.99**
M_3	**Z_1**	1.10	1.17	1.06	**1.11**	1.16	1.23	1.12	**1.17**	1.01	1.08	0.97	**1.02**	1.07	1.14	1.03	**1.08**
	Z_2	1.07	1.15	1.04	**1.09**	1.13	1.21	1.10	**1.15**	0.98	1.06	0.95	**1.00**	1.04	1.12	1.01	**1.06**
M_4	**Z_1**	1.14	1.20	1.14	**1.16**	1.20	1.26	1.19	**1.22**	1.05	1.13	1.04	**1.07**	1.11	1.17	1.10	**1.13**
	Z_2	1.12	1.17	1.12	**1.13**	1.18	1.23	1.18	**1.19**	1.03	1.08	1.03	**1.04**	1.09	1.14	1.09	**1.10**
N		**1.11**	**1.16**	**1.10**		**1.17**	**1.22**	**1.16**		**1.01**	**1.07**	**1.00**		**1.07**	**1.13**	**1.06**	
		MxN			**M**	**MxN**			**M**	**MxN**			**M**	**MxN**			**M**
M	**M_1**	1.17	1.24	1.20	**1.20**	1.23	1.30	1.26	**1.26**	1.08	1.15	1.11	**1.11**	1.14	1.21	1.17	**1.17**
	M_2	1.04	1.06	1.02	**1.04**	1.10	1.12	1.08	**1.10**	0.94	0.96	0.92	**0.94**	1.00	1.02	0.98	**1.00**
	M_3	1.08	1.16	1.05	**1.10**	1.14	1.22	1.11	**1.16**	0.99	1.07	0.96	**1.01**	1.05	1.13	1.02	**1.07**
	M_4	1.13	1.19	1.12	**1.14**	1.19	1.25	1.18	**1.20**	1.04	1.10	1.03	**1.05**	1.10	1.16	1.09	**1.11**
		NxZ			**Z**	**NxZ**			**Z**	**NxZ**			**Z**	**NxZ**			**Z**
Z	**Z_1**	1.12	1.17	1.10	**1.13**	1.18	1.23	1.16	**1.19**	1.03	1.08	1.01	**1.04**	1.09	1.14	1.07	**1.10**
	Z_2	1.09	1.15	1.09	**1.11**	1.15	1.21	1.15	**1.17**	1.00	1.06	1.00	**1.02**	1.06	1.12	1.06	**1.08**
Control		**0.62**				**0.63**				**0.52**				**0.51**			
		S.Em ±		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**		**S.Em ±**		**CD at 5 %**	
M (MP)		0.05		0.01		0.03		0.03		0.10		0.05		0.01		0.03	
N (SP)		0.04		0.02		0.04		0.01		0.03		0.03		0.01		0.03	
Z (SSP)		NS		0.01		NS		0.01		NS		NS		0.01		NS	
M x N		NS		0.04		NS		0.02		NS		NS		0.02		NS	
M x Z		NS		0.02		NS		0.02		NS		NS		0.02		NS	
N x Z		NS		0.02		NS		0.02		NS		NS		0.02		NS	
M x N x Z		NS		0.04		NS		0.04		NS		NS		0.04		NS	
Control vs Rest		0.08		0.04		0.07		0.10		0.18		0.09		0.03		0.06	

NOTE:
NS : Non significant

Main plot	:	*Soil nitrogen management (M)*	*M_1*	:	*100 % RDF + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1}*	*M_2*	:	*75 % RDN*	*M_3*	: *100 % RDN* *M_4 : 125 % RDN*
Sub plot	:	*Foliar spray of nano nitrogen (N)*	*N_1*	:	*FS of nano N @ 2000 ppm*	*N_2*	:	*FS of nano N @ 4000 ppm*	*N_3*	: *FS of nano N @ 6000 ppm*
Sub-sub plot	:	*Foliar spray of nano zinc (Z)*	*Z_1*	:	*FS of nano Zn @ 2000 ppm*	*Z_2*	:	*FS of nano Zn @ 3000 ppm*		

4. CONCLUSION

Nano-fertilizer has the potential to improve soil fertility and crop production. Moreover, nano fertilizers have great impact on the soil, can reduce the toxicity of the soil and decrease the frequency of fertilizer application. Application of 125 per cent RDN along with foliar spray of nano N @ 4000 ppm at active tillering& panicle initial stages and foliar spray of nano Zn @ 2000 ppm at active tillering stage of paddy was found to be on par with 100 per cent RDN along with foliar spray of nano N @ 4000 ppm at active tillering& panicle initial stages and foliar spray of nano Zn @ 2000 ppm at active tillering stage in terms of crop yield and soil available nutrients. Hence for effective management of nano fertilizers in paddy, the application of 100 per cent RDN along with foliar spray of nano N @ 4000 ppm and foliar spray of nano Zn @ 2000 ppm was recommended [13-16].

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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