



Effect of Nano Nitrogen and Nano Zinc on Growth and Yield of Paddy in Paddy-Paddy Cropping System

**Sahana^{a*}, M. V. Ravi^{b++}, K. Narayana Rao^{a++},
J. Vishwanath^{c#}, M. R. Umesh^{d†} and Mahadevaswamy^{e++}**

^a Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Raichur-584104, Karnataka, India.

^b Department of Soil Science and Agricultural Chemistry, Collage of Agriculture, Gangavathi, Karnataka, India.

^c AICRP on Management of Salt Affected Soils, Agriculture Research Station, Gangavathi, Karnataka, India.

^d Department of Agronomy, AICRP on Sunflower, MARS, Department of Agronomy, University of Agricultural Sciences, Raichur-584104, Karnataka, India.

^e Department of Agricultural Microbiology, University of Agricultural Sciences, Raichur-584104, Karnataka, India.

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

An investigation on nano nitrogen and nano zinc with different levels of nitrogen approaches on growth and yield of paddy was conducted during *rabi* and *kharif* seasons of 2020-21 and 2021-22 at Krishi Vigyana Kendra, Gangavathi, Koppal, Karnataka, India. The experiment was laid out in split-

⁺⁺ Professor and Head;

[#] Principal Scientist and Head;

[†] Scientist;

^{*}Corresponding author: E-mail: sahanachinnur7576@gmail.com;

split plot design with three replications, which consisted of four levels of nitrogen in main plots, three levels of nano nitrogen in sub plots and two levels of nano zinc in sub-sub plots. The treatment with application of 125 per cent Recommended Dose of Nitrogen (RDN) has recorded significantly taller plants (97.11 and 96.54 cm), higher number of tillers hill⁻¹ (19.65 and 18.14) and total dry matter (70.06 and 64.54 g hill⁻¹) at harvest stage of crop and the Soil Plant Analysis Development (SPAD) values (46.69 and 42.60) and Normalized Difference Vegetation Index (NDVI) values (0.85 and 0.82) at flowering stage of crop, Similarly, foliar spray of nitrogen @ 4000 ppm has recorded significantly higher plant height (95.44 and 91.33 cm), higher number of tillers hill⁻¹ (17.75 and 16.01), total dry matter (66.84 and 62.31 g hill⁻¹) SPAD values at flowering stage (44.89 and 41.29), NDVI values at flowering stage (0.81 and 0.74), grain yield (5623 & 6840 kg ha⁻¹) and straw yield (5352 and 6581 kg ha⁻¹). Interaction effect showed non-significant effect with different combination treatments.

Keywords: Nano nitrogen; nano zinc; foliar spray; growth.

1. INTRODUCTION

Sustainability of natural resources such as soil and water for crops production is a major challenge with burgeoning population pressure. There is a need to balance between increasing crop production without compromising soil health and environmental sustainability. In Asia, rice is the principal staple crop where ~90 percent of the global rice being grown and consumed. In India, it occupies ~43.8 m ha of cultivable area with production of ~118.87 mt [1]. Intensive mono-cropped system of rice cultivation has commenced to show declining trend in rice yield, where imbalance nutrient management and decreasing soil organic matter are the major accountable factors for the declining the rice yield [2].

Fertilizers are indispensable in agricultural production system. Application of fertilizers started in 1960's which closely coincided with the introduction of fertilizer responsive varieties in Indian agriculture. Although fertilizer application remarkably improved the crop growth and enhanced the yields of several crops but the yields got plateaued due to the low fertilizer response ratio, imbalanced fertilization and increased intensities of micronutrient deficiencies across the country. Within the set of challenges faced by the present agriculture system, imbalanced fertilization is one of the most critical factor to be considered for nitrogen (N) management. Since N fertilization reveals universal response in crops besides low price of urea due to decontrol (subsidized rate), farmers started the use of nitrogenous fertilizers particularly urea irrationally, which has led to the current nitrogen: phosphorus: potassium (NPK) ratio of 8.2: 3.2: 1 while optimal ratio is stipulated as 4: 2: 1 in cereals. This is very serious issue

causing nitrate pollution in ground water and eutrophication in aquatic system. This necessitates to develop slow release fertilizers to regulate the nitrification processes thereby N availability be sustained during the crop period.

Nowadays, application of nano particles (NPs) is gaining importance in agriculture. Nanotechnology deals with small particles with the dimension of 1-100 nm (one billionth of a meter). These particles have high surface mass ratio and are capable of improving the efficiency of agricultural inputs including fertilizers. Nano fertilizers have unique physico-chemical properties and the potential to enhance the plant metabolism [3]. The nano fertilizers or nano encapsulated nutrients might have the properties that are effective to crops, release the nutrients on demand, controlled release of chemical fertilizers that regulate the plant growth and boost the target activity [4]. Nanotechnology has potential to develop slow release efficient fertilizers [5] which eventually reduce the nutrient losses and augment the existing fertilizer use efficiency.

Therefore, achieving sustainable agriculture with more yields besides maintaining the environmental and soil health is the goal of researchers in agriculture. In such manner, utilization of chemical fertilizers has long been condemned because of their harmful impacts on the environment and quality of agricultural products and there is a need to explore better alternatives such as nano particles with small size and large surface area are expected to be the ideal candidates for use as fertilizers in crops to improve fertilizer use efficiency and to minimize the detrimental effects of fertilizers on the environment. Use of nano N and nano zinc (Zn) fertilizers are the better alternatives to

increase nutrient use efficiency. In the view of above, the newly introduced nano N and nano Zn fertilizers by Indian Farmers Fertiliser Cooperative Limited (IFFCO Ltd). These products have been researched and developed indigenously at the IFFCO Nano Biotechnology Research Centre (NBRC) at Kalol Unit, Gujarat. Nano nitrogen contains 4% of N and nano zinc contains 1% of Zn.

1.1 Objective of the Experiment

To evaluate the effect of nano nitrogen and nano zinc on growth and yield of transplanted paddy - paddy cropping system.

2. MATERIALS AND METHODS

2.1 Experimental Site and Soil

The field experiments were conducted in Krishi Vigyana Kendra, Gangavathi (Dist: Koppal), India during *rabi* season of 2020-2021 and *kharif and rabi* season of 2021-2022. The experiment site situated 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 electrical conductivity (EC) (1.26dS m⁻¹) and high in organic carbon (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 diethylene triamine penta acetic acid (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.

2.2 Salient Features of the Cultivar RNR-15048

The variety used was RNR 15048 (Telengana Sona). This paddy variety has low glycemic index of 51 and 5 per cent more protein compared to BPT-5204. It has unique grain size, short slender, high grain yield potential, good cooking quality and above all robust blast resistance characteristics. One of the striking qualities of this paddy variety is that it can be cultivated during both *kharif* and *rabi* seasons in a short duration of about 125 days.

2.3 Experimental Details

The experiment was laid out in a split-split plot design with twenty four treatments and three replications. The details of treatment are shown in Table 1.

Recommended dose of P and K was applied through conventional fertilizer and farmyard manure (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.

2.4 Growth and Yield Measurements

The plant height and number of tillers hill⁻¹ of paddy in each season was recorded at panicle initiation and crop harvest stage. Chlorophyll meter readings were recorded at active tillering, panicle initiation and flowering stages. The top most fully expanded leaf was chosen for SPAD measurement, as described by Babu et al. (2000). The SPAD readings were taken at random for each plot and the average was noted.

Table 1. Treatment details

Main plot: Soil nitrogen management (M)	Subplot: Foliar spray (FS) of nano nitrogen (N)	Subplot: Foliar spray (FS) of nano zinc (Z)
M ₁ : 100 % RDF (ZnSO ₄ ·7H ₂ O @ 25 kg ha ⁻¹)	N ₁ : FS of nano N @ 2000 ppm (2 ml L ⁻¹)	Z ₁ : FS of nano Zn @ 2000 ppm (2 ml L ⁻¹)
M ₂ : 75 % RDN	N ₂ : FS of nano N @ 4000 ppm (4 ml L ⁻¹)	Z ₂ : FS of nano Zn @ 3000 ppm (3 ml L ⁻¹)
M ₃ : 100 % RDN	N ₃ : FS of nano N @ 6000 ppm (6 ml L ⁻¹)	
M ₄ : 125 % RDN		

RDF: Recommended Dose Fertilizer

RDN: Recommended Dose Nitrogen

The Green Seeker hand held optical sensor unit (Trimble Navigation Limited, Sunnyvale, CA, USA) was used for NDVI measurement in the study. The sensor emits brief bursts of red and infrared light and then measures the amount of each that is reflected back. The instrument was held 2-3 feet above the plant canopy and moved around the plot randomly along the crop canopy to measure the average NDVI value for each plot. The observations were recorded at active tillering, panicle initiation and flowering stages of crop. In 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 hectare (kg ha^{-1}).

2.5 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 [6].

3. RESULTS AND DISCUSSION

The data on growth, yield and nutrient uptake paddy are shown in Table 2 to 5. There was a slight difference in these parameters during both *kharif* and *rabi* season experiments, but the pattern of response was similar. Hence, only pooled data of the *rabi* season and one year data of *kharif* season have been used to emphasize the results.

3.1 Plant Height (cm) of Paddy

Among different nitrogen levels, 125 per cent RDN (M_4) recorded higher plant height 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 plant height was recorded by foliar spray of nano N @ 4000 ppm (N_2 : 79.36 & 95.44 and 73.75 & 91.33 cm at PI & HS during *rabi* and *kharif* season, respectively) followed by FS of nano N @ 2000 ppm (N_1) and 6000 ppm (N_3).

There was no significance difference among the foliar spray of nano Zn but higher plant height was recorded by the FS of nano Zn @ 2000 ppm at PI and HS of paddy crop (77.89 & 93.97 and 72.35 & 89.59 cm during *rabi* and *kharif* season, respectively) followed by foliar spray of nano Zn

@ 3000 ppm (Table 2). While, absolute control registered a lower plant height at PI and HS of paddy crop (65.19 & 80.40 and 63.99 & 79.34 cm during *rabi* and *kharif* season, respectively).

Interaction effect among different levels of nitrogen, foliar spray of nano N and nano Zn showed non-significant difference but the higher plant height (Table 2) was recorded with the combination of 125 % RDN along with foliar spray of nano N @ 4000 ppm and nano Zn @ 2000 ppm at PI and HS of paddy crop (86.11 & 101.13 and 81.80 & 100.58 during *rabi* and *kharif* season, respectively) while, lower plant height was recorded with the combination of 75 % RDN along with foliar spray of nano N @ 6000 ppm and nano Zn @ 3000 ppm (70.83 & 87.81 and 65.15 & 80.78 during *rabi* and *kharif* season, respectively).

During *rabi* and *kharif* season of the study, an increasing trend in plant height was observed across the growth stages of paddy in all the treatments. Different levels of nitrogen affected the plant height significantly with the age of paddy crop and recorded higher in 125 per cent RDN (M_4) followed by 100 per cent RDF with $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$ at 25 kg ha^{-1} (M_1), 100 per cent RDN (M_3) and 75 per cent RDN (M_1). This could be due to increased vegetative growth of plant with higher levels of N supplied to plant. In parallel, Reddy et al. [7] reported that increased rates of N application significantly improved the plant height as compared to control.

Improved plant height under foliar spray of nano N @ 4000 ppm and foliar spray of nano Zn @ 2000 ppm was accrued due to sufficient nutrients supply as per crop demand as compared to FS of nano N @ 2000 ppm, 6000 ppm and foliar spray of nano Zn @ 3000 ppm. Increase in the plant height could be ascribed to adequate supply of nitrogen and zinc which accelerate the activity of enzyme and auxin metabolism in the plant, which in turn enlarge the cell and cell elongation might resulted in taller plants. This is in conformity with the works of Torres-Olivar et al. [8] and Nithya et al. [9]. Benzon et al. [10] revealed that plant height was more enhanced when nano-fertilizer was combined with conventional ones due to the reason that nano fertilizer can either provide nutrients for the plant or aid in the transport or absorption of available nutrients resulting in better crop growth.

The enhancement in plant height by application of 125 per cent RDN along with foliar spray of nano N @ 4000 ppm with foliar spray of nano Zn

@ 2000 ppm ($M_4N_2Z_1$) over other treatments might be due to enhanced availability of both macro and micro nutrients besides improvement in soil microbial activity. The enhanced uptake of these nutrients might have resulted in increased vegetative growth of plant.

3.2 Number of Tillers hill⁻¹

Significant difference with respect to number of tillers hill⁻¹ was observed with different levels of nitrogen and foliar spray of nano N across the growth stages of paddy. Similar to plant height, number of tillers hill⁻¹ increased significantly by 125 per cent RDN at PI and FS of paddy crop (M_4 : 17.03 & 19.65 and 15.49 & 18.14 during *rabi* and *kharif* season, respectively) followed by M_1 , M_3 and M_2 . Similarly significant higher number of tillers hill⁻¹ was recorded in different stages of paddy crop by foliar spray of nano N @ 4000 ppm (N_2 : 15.32 & 17.75 and 13.67 & 16.01 during *rabi* and *kharif* season, respectively) followed by foliar spray of nano N @ 2000 ppm and 6000 ppm (Table 3).

Foliar spray of nano Zn @ 2000 ppm recorded higher number of tillers hill⁻¹ (14.49 & 16.83 and 12.79 & 14.95 at PI and FS of paddy crop during *rabi* and *kharif* season, respectively), which was on par with the foliar spray of nano Zn @ 3000 ppm (Table 3). While, absolute control registered lower number of tillers hill⁻¹ at PI and FS of paddy crop (9.42 & 11.24 and 9.80 & 11.37 during *rabi* and *kharif* season, respectively).

Combined application of different levels of nitrogen, foliar spray of nano N and nano Zn showed non-significant difference but higher number of tillers hill⁻¹ (Table 3) was recorded with the combination of 125 % RDN along with foliar spray of nano N @ 4000 ppm and nano Zn @ 2000 ppm (18.43 & 21.20 and 16.98 & 20.00 during *rabi* and *kharif* season, respectively), while lower number of tillers hill⁻¹ was recorded with the combination of 75 % RDN along with foliar spray of nano N @ 6000 ppm and nano Zn @ 3000 ppm (11.46 & 13.47 and 9.57 & 11.18 during *rabi* and *kharif* season, respectively). It was probably due to increased supply of nitrogen and zinc to plants, which have accelerated the activity of enzymes involved in photosynthesis, carbohydrates metabolism, protein synthesis, cell division and cell elongation. This is in conformity with the work of Beerasha [11] and Uma [12]. Wijebandara [13] reported that the availability of required quantity of N for long time was probably responsible for producing a greater number of effective tillers as is the case with higher levels of

N applied in the present study. The findings are in line with the observations of Sankalpa [14] who reported that increased number of tillers per hill could be expected up to 40 % N in excess of RDF N. Manzoor et al. [15], Wijebandara [13] and Choudhary and Pandey [16] also reported similar observations.

The significant increase in number of tillers per hill⁻¹ by nano N could be expected up to foliar spray of 4000 ppm N. Kumari et al. [17] also reported increase in number of productive tillers up to a certain level of N (120 kg ha⁻¹) and not beyond that. The results are in agreement with the findings of Manzoor et al. [15] and Wijebandara [13]. Nano-fertilizers induced nitrate reductase and increased activity of chloroplast [18], rubisco [19] and antioxidant enzyme system [20] that might be the possible underlying mechanism for enhanced growth and increase in number of tillers.

3.3 Total Dry Matter Production (g hill⁻¹)

Application of 125 per cent RDN recorded higher total dry matter production at PI and HS of paddy crop (27.55 & 70.06 and 24.01 & 64.54 g hill⁻¹ during *rabi* and *kharif* season, respectively) followed by 100 per cent RDF + ZnSO₄.7H₂O @ 25 kg ha⁻¹, 100 per cent RDN and 75 per cent RDN (Table 4). On the other hand, significantly higher total dry matter production was recorded in all the stages of paddy crop by FS of nano N @ 4000 ppm (26.26, & 66.84 and 23.53 & 62.31 g hill⁻¹ during *rabi* and *kharif* season, respectively) as compared to FS of nano N @ 2000 ppm and 6000 ppm.

No significance difference was recorded among the FS of nano Zn but higher total dry matter production was recorded by the FS of nano Zn @ 2000 ppm at PI and HS of paddy crop (25.41 & 64.67 and 22.76 & 60.29 g hill⁻¹ during *rabi* and *kharif* season, respectively) followed by FS of nano Zn @ 3000 ppm.

Combined application of 125 per cent RDN along with FS of nano N @ 4000 ppm and nano Zn @ 2000 ppm recorded higher total dry matter production at PI and HS of paddy crop (28.78 & 73.18 and 25.08 & 67.41g hill⁻¹ during *rabi* and *kharif* season, respectively) while, lower total dry matter production was recorded with the combination of 75 per cent RDN along with FS of nano N @ 2000 ppm and nano Zn @ 3000 ppm at PI and HS of paddy crop (22.24 & 58.04 and 19.89 & 54.51 g hill⁻¹ during *rabi* and *kharif* season, respectively). Control treatment

recorded significantly lower total dry matter production values at PI and HS of paddy crop (17.94 & 47.33 and 18.46 & 47.25 g hill⁻¹ during *rabi* and *kharif* season, respectively).

One of the most important growth parameters which is a measure of total photosynthesis and respiratory tissues is total dry matter production. Total dry weight of plant was increased over time with the advancement of crop age. There exists a direct relation between plant height and number of tillers with dry matter production. The treatment with 125 per cent RDN (M₄) was associated with increased plant height and number of tillers.

On the other hand, FS of nano N also significantly increased the total dry matter production at all stages of crop growth due to cumulative vigorous growth which in turn put forth more photosynthetic surface, chlorophyll formation, biomass and more nutrient uptake. Increased crop growth rate is attributed to higher dry matter accumulation at periodic intervals. These results are in corroboration with the findings of Jafarzadeh *et al.* [21], Mahmoodzadeh *et al.* [22], Kumar *et al.* [23], Benzon *et al.* [10], Hafeez *et al.* [24] and Aziz *et al.* [25].

3.4 Chlorophyll Content

Higher SPAD values were recorded at different growth stages with application of 125 per cent RDN at AT, PI and FS of paddy crop (31.57, 43.59 & 46.69 and 29.18, 40.19 & 42.60 during *rabi* and *kharif* season, respectively) as compared to other treatment (Table 5). Similarly significant higher SPAD values were recorded at AT, PI and FS of paddy crop by FS of nano N @ 4000 ppm (30.42, 41.86 & 44.89 and 27.96, 38.73 & 41.29 during *rabi* and *kharif* season, respectively) followed by to FS of nano N @ 2000 ppm and FS of nano N @ 6000 ppm.

Among FS of nano Zn, higher SPAD values were recorded by the FS of nano Zn @ 2000 ppm (29.94, 41.16 & 44.14 and 27.49, 38.11 & 40.59 during *rabi* and *kharif* season, respectively) which was on par with FS of nano Zn @ 3000 ppm. Control treatment recorded significantly lower SPAD values at AT, PI and FS of paddy crop (24.83, 31.06 & 35.14 and 24.86, 29.38 & 33.44 during *rabi* and *kharif* season, respectively).

Interaction effect among different nitrogen levels, FS of nano N and FS of nano Zn showed non-significant difference but the higher SPAD values

was recorded with the combination of 125 per cent RDN along with FS of nano N @ 4000 ppm and nano Zn @ 2000 ppm (32.04, 44.24 & 47.40 and 29.64, 40.79 & 43.27 during *rabi* and *kharif* season, respectively) while, lower SPAD values was recorded with the combination of 75 per cent RDN along with FS of nano N @ 6000 ppm and nano Zn @ 3000 ppm (27.54, 37.40 & 40.25 and 24.86, 35.06 & 37.54 during *rabi* and *kharif* season, respectively) at AT, PI and FS of paddy crop.

SPAD values indicates the greenness *i.e.*, chlorophyll content of leaves. Higher SPAD value obtained due to the absorption and assurance of sufficient supply of nutrients mainly the nitrogen to the leaves [26]. Nano fertilizers improved the N, P and K uptake in the crop as indicated in Table 5 and 7. As nitrogen is the major component in the chlorophyll synthesis, this might have contributed to higher chlorophyll content in nano fertilizer applied treatments. These results are in accordance with Rose *et al.* [27]. In addition, application of nano Zn also promotes the synthesis of chlorophyll, which acts as a structural and catalytic component of proteins, enzymes and as co-factor for normal development of pigment biosynthesis [28].

3.5 Normalized Difference Vegetation Index (NDVI)

The data pertaining to NDVI differed significantly among different nitrogen levels and FS of nano N (Table 6). Among different nitrogen levels 125 per cent RDN recorded higher NDVI values at AT, PI and FS of paddy crop (0.53, 0.72 & 0.85 and 0.49, 0.68 & 0.82 during *rabi* and *kharif* season, respectively) followed by M₁, M₃ and M₂. Similarly significant higher NDVI values were recorded in different stages of paddy crop by FS of nano N @ 4000 ppm (0.50, 0.68 & 0.81 and 0.46, 0.62 & 0.74 during *rabi* and *kharif* season, respectively) as compared to FS of nano N @ 2000 ppm and 6000 ppm.

No significance difference was recorded among the FS of nano Zn but higher NDVI values were recorded by the FS of nano Zn @ 2000 ppm at AT, PI and FS of paddy crop (0.48, 0.67 & 0.80 and 0.44, 0.60 & 0.72 during *rabi* and *kharif* season, respectively) as compared to FS of nano Zn @ 3000 ppm. Control treatment recorded significantly lower NDVI values at AT, PI and FS of paddy crop (0.28, 0.43 & 0.57, and 0.26, 0.36 & 0.51 during *rabi* and *kharif* season, respectively).

Table 2. Plant height (cm) at panicle initiation and harvest stages of paddy as 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 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	78.47	79.86	76.38	78.24	73.67	75.35	71.60	73.54	94.77	96.16	92.68	94.54	91.72	93.81	89.15	91.56
	Z ₂	76.88	78.76	74.70	76.78	72.12	74.18	71.35	72.55	93.18	95.07	90.99	93.08	89.79	92.36	88.83	90.32
M ₂	Z ₁	73.61	76.07	71.62	73.77	66.83	69.02	65.54	67.13	90.60	93.06	88.61	90.76	82.86	85.58	81.26	83.24
	Z ₂	72.81	73.78	70.83	72.48	66.44	68.12	65.15	66.57	89.80	90.78	87.81	89.46	82.38	84.46	80.78	82.54
M ₃	Z ₁	76.68	78.76	74.60	76.68	70.19	70.70	68.51	69.80	92.68	94.77	90.60	92.68	87.02	87.66	84.94	86.54
	Z ₂	75.37	77.48	73.11	75.32	69.02	70.31	67.73	69.02	91.37	93.48	89.11	91.32	85.58	87.18	83.98	85.58
M ₄	Z ₁	82.24	86.11	80.25	82.87	78.06	81.80	76.89	78.92	97.26	101.13	95.27	97.89	95.98	100.58	94.55	97.04
	Z ₂	81.15	84.02	78.76	81.31	77.28	80.51	76.51	78.10	96.16	99.04	93.78	96.33	95.03	98.99	94.08	96.03
N		77.15	79.36	75.03		71.70	73.75	70.41		93.23	95.44	91.11		88.80	91.33	87.20	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	77.67	79.31	75.54	77.51	72.89	74.77	71.48	73.05	93.98	95.62	91.84	93.81	90.75	93.08	88.99	90.94
	M ₂	73.21	74.93	71.23	73.12	66.64	68.57	65.35	66.85	90.20	91.92	88.21	90.11	82.62	85.02	81.02	82.89
	M ₃	76.03	78.12	73.85	76.00	69.60	70.51	68.12	69.41	92.03	94.13	89.85	92.00	86.30	87.42	84.46	86.06
	M ₄	81.69	85.06	79.51	82.09	77.67	81.15	76.70	78.51	96.71	100.09	94.52	97.11	95.50	99.79	94.31	96.54
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	77.75	80.20	75.71	77.89	72.19	74.22	70.64	72.35	93.83	96.28	91.79	93.97	89.40	91.91	87.48	89.59
	Z ₂	76.55	78.51	74.35	76.47	71.22	73.28	70.19	71.56	92.63	94.59	90.42	92.55	88.20	90.75	86.92	88.62
Control		65.19				63.99				80.40				75.34			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M		0.99		3.31		0.58		2.01		0.64		2.21		0.57		1.96	
N		0.96		2.19		0.64		1.91		0.95		2.13		0.98		2.34	
Z		0.66		NS		0.64		NS		0.92		NS		0.77		NS	
M x N		1.93		NS		1.27		NS		1.89		NS		1.96		NS	
M x Z		1.33		NS		1.29		NS		1.85		NS		1.54		NS	
N x Z		1.15		NS		1.12		NS		1.60		NS		1.33		NS	
M x N x Z		2.30		NS		2.23		NS		3.20		NS		2.66		NS	
Control vs Rest		3.52		6.08		2.13		3.68		2.34		4.05		2.08		3.60	

NOTE: NS : Non significant

Main plot : Soil nitrogen management (M) M₁ : 100 % RDF (ZnSO₄.7H₂O @ 25 kg ha⁻¹) M₂ : 75 % RDN M₃ : 100 % RDN M₄ : 125 % RDN
 Sub plot : Foliar spray of nano nitrogen (N) N₁ : FS of nano N @ 2000 ppm N₂ : FS of nano N @ 4000 ppm N₃ : FS of nano N @ 6000 ppm
 Sub-sub plot : Foliar spray of nano zinc (Z) Z₁ : FS of nano Zn @ 2000 ppm Z₂ : FS of nano Zn @ 3000 ppm

Table 3. Number of tillers per hill at panicle initiation and harvest of paddy stages as 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 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	14.71	15.55	13.87	14.71	13.02	13.91	12.13	13.02	17.07	18.01	16.13	17.07	15.21	16.25	14.16	15.21
	Z ₂	14.47	15.31	13.75	14.51	12.76	13.66	12.00	12.81	16.81	17.72	15.98	16.84	14.91	15.95	14.01	14.96
M ₂	Z ₁	12.42	13.38	11.58	12.46	10.59	11.62	9.70	10.64	14.53	15.60	13.57	14.57	12.37	13.57	11.33	12.42
	Z ₂	11.94	13.02	11.46	12.14	10.08	11.23	9.57	10.30	14.00	15.19	13.47	14.22	11.78	13.12	11.18	12.03
M ₃	Z ₁	13.50	14.47	12.66	13.54	11.74	12.76	10.85	11.79	15.80	16.80	14.78	15.79	13.72	14.91	12.67	13.77
	Z ₂	13.50	14.71	12.30	13.50	11.74	13.02	10.47	11.74	15.73	17.07	14.40	15.73	13.72	15.21	12.22	13.72
M ₄	Z ₁	16.87	18.43	16.39	17.23	15.32	16.98	14.81	15.70	19.49	21.20	18.93	19.88	17.89	20.00	17.29	18.39
	Z ₂	16.51	17.71	16.27	16.83	14.93	16.21	14.68	15.27	19.07	20.41	18.81	19.43	17.44	19.10	17.14	17.89
N		14.24	15.32	13.53		12.52	13.67	11.77		16.56	17.75	15.76		14.63	16.01	13.75	14.24
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	14.59	15.43	13.81	14.61	12.89	13.78	12.06	12.91	16.94	17.87	16.06	16.95	15.06	16.10	14.09	15.08
	M ₂	12.18	13.20	11.52	12.30	10.34	11.42	9.64	10.47	14.26	15.39	13.52	14.39	12.08	13.34	11.26	12.22
	M ₃	13.50	14.59	12.48	13.52	11.74	12.89	10.66	11.76	15.77	16.93	14.59	15.76	13.72	15.06	12.45	13.74
	M ₄	16.69	18.07	16.33	17.03	15.13	16.59	14.74	15.49	19.28	20.80	18.87	19.65	17.67	19.55	17.22	18.14
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	9.80	10.69	9.18	9.89	8.96	9.22	8.77	8.98	14.38	15.46	13.62	14.49	12.67	13.82	11.87	12.79
	Z ₂	9.58	10.47	9.04	9.69	8.84	9.10	8.71	8.89	14.11	15.19	13.44	14.25	12.38	13.53	11.68	12.53
Control		4.90				4.85				9.42				9.80			
		S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	
M		0.13		0.45	0.15		0.54	0.22		0.77	0.16		0.54				
N		0.11		0.32	0.07		0.21	0.20		0.58	0.19		0.56				
Z		0.09		NS	0.09		NS	0.15		NS	0.10		NS				
M x N		0.21		NS	0.14		NS	0.39		NS	0.38		NS				
M x Z		0.17		NS	0.18		NS	0.29		NS	0.21		NS				
N x Z		0.15		NS	0.15		NS	0.25		NS	0.18		NS				
M x N x Z		0.30		NS	0.31		NS	0.50		NS	0.36		NS				
Control vs Rest		0.48		0.83	0.57		0.98	0.81		1.41	0.58		1.00				

NOTE: NS : Non significant

Main plot : Soil nitrogen management (M)

M₁ : 100 % RDF (ZnSO₄.7H₂O @ 25 kg ha⁻¹)M₂ : 75 % RDNM₃ : 100 % RDN M₄ : 125 % RDN

Sub plot : Foliar spray of nano nitrogen (N)

N₁ : FS of nano N @ 2000 ppmN₂ : FS of nano N @ 4000 ppmN₃ : FS of nano N @ 6000 ppm

Sub-sub plot : Foliar spray of nano zinc (Z)

Z₁ : FS of nano Zn @ 2000 ppmZ₂ : FS of nano Zn @ 3000 ppm

Table 4. Total dry matter production (g hill⁻¹) at flowering and harvest stages of paddy as influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc

MxNxZ		Panicle initiation								At harvest							
		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	25.79	27.02	24.60	25.80	23.47	24.59	22.39	23.48	64.94	68.06	61.95	64.98	61.03	63.96	58.23	61.07
	Z ₂	25.18	26.37	25.57	25.71	22.92	24.00	22.28	23.06	63.42	66.41	64.39	64.74	59.61	62.42	60.52	60.85
M ₂	Z ₁	22.71	23.30	22.71	22.75	20.31	20.83	20.30	20.34	59.27	60.79	59.26	59.37	55.66	57.09	55.66	55.76
	Z ₂	22.47	22.66	22.24	22.62	20.09	20.26	19.89	20.22	58.65	59.14	58.04	59.01	55.08	55.54	54.51	55.43
M ₃	Z ₁	25.29	26.89	23.73	25.31	23.02	24.48	21.60	23.03	63.70	67.73	59.77	63.73	59.25	63.00	55.59	59.28
	Z ₂	24.63	26.45	23.41	24.83	22.41	24.07	21.31	22.60	62.02	66.62	58.96	62.53	57.69	61.97	54.84	58.17
M ₄	Z ₁	27.43	28.78	27.09	27.77	23.90	25.08	23.61	24.19	69.73	73.18	68.89	70.60	64.24	67.41	63.46	65.04
	Z ₂	26.62	28.63	26.78	27.34	23.19	24.94	23.33	23.82	67.69	72.80	68.09	69.52	62.36	67.06	62.72	64.05
N		25.02	26.26	24.52		22.41	23.53	21.84		63.68	66.84	62.42		59.37	62.31	58.19	
		MxN				M				MxN				M			
M	M ₁	25.48	26.70	25.08	25.76	23.19	24.30	22.33	23.27	64.18	67.23	63.17	64.86	60.32	63.19	59.37	60.96
	M ₂	22.59	22.98	22.48	22.68	20.20	20.55	20.10	20.28	58.96	59.96	58.65	59.19	55.37	56.32	55.09	55.59
	M ₃	24.96	26.67	23.57	25.07	22.72	24.27	21.45	22.81	62.86	67.17	59.36	63.13	58.47	62.48	55.22	58.72
	M ₄	27.02	28.70	26.93	27.55	23.55	25.01	23.47	24.01	68.71	72.99	68.49	70.06	63.30	67.24	63.09	64.54
		NxZ				Z				NxZ				Z			
Z	Z ₁	25.30	26.50	24.42	25.41	22.67	23.74	21.87	22.76	64.41	67.44	62.16	64.67	60.05	62.87	57.95	60.29
	Z ₂	24.73	26.03	24.62	25.12	22.16	23.32	21.81	22.43	62.94	66.24	62.67	63.95	58.68	61.75	58.44	59.62
Control		17.94				18.46				47.33				47.25			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M		0.23		0.81		0.34		1.16		0.67		2.33		0.51		1.78	
N		0.34		1.02		0.23		0.70		0.66		1.98		0.68		2.03	
Z		0.28		NS		0.19		NS		0.64		NS		0.55		NS	
M x N		0.68		NS		0.47		NS		1.32		NS		1.35		NS	
M x Z		0.57		NS		0.37		NS		1.28		NS		1.10		NS	
N x Z		0.49		NS		0.32		NS		1.11		NS		0.95		NS	
M x N x Z		0.98		NS		0.65		NS		2.21		NS		1.91		NS	
Control vs Rest		0.86		1.48		1.24		2.14		2.48		4.28		1.89		3.26	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M) M₁ : 100 % RDF (ZnSO₄.7H₂O @ 25 kg ha⁻¹) M₂ : 75 % RDN M₃ : 100 % RDN M₄ : 125 % RDN
 Sub plot : Foliar spray of nano nitrogen (N) N₁ : FS of nano N @ 2000 ppm N₂ : FS of nano N @ 4000 ppm N₃ : FS of nano N @ 6000 ppm
 Sub-sub plot : Foliar spray of nano zinc (Z) Z₁ : FS of nano Zn @ 2000 ppm Z₂ : FS of nano Zn @ 3000 ppm

Table 5. Leaf chlorophyll content (SPAD) at active tillering, panicle initiation and flowering stages of paddy as influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc

MxNxZ	Active tillering																								Panicle initiation												Flowering															
	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	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	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ												
M ₁	Z ₁	30.07	30.98	29.53	30.19	27.42	28.31	26.89	27.54	41.15	42.54	40.71	41.46	38.28	39.44	37.58	38.43	44.07	45.59	43.70	44.45	40.58	41.90	39.80	40.76	M ₂	Z ₁	29.60	30.60	29.38	29.86	26.97	27.94	26.75	27.22	40.55	41.99	40.33	40.96	37.68	38.96	37.40	38.01	43.45	45.03	43.32	43.93	39.91	41.35	39.59	40.28	
	Z ₂	28.16	28.62	27.60	28.13	25.47	25.91	24.92	25.43	38.60	39.43	37.77	38.60	35.85	36.43	35.13	35.81	41.43	42.33	40.62	41.46	38.46	39.13	37.63	38.40																											
M ₃	Z ₁	27.84	28.45	27.54	27.94	25.16	25.74	24.86	25.25	38.35	39.22	37.40	38.33	35.44	36.21	35.06	35.57	41.16	42.11	40.25	41.18	37.98	38.87	37.54	38.13	M ₄	Z ₁	29.79	30.62	28.91	29.77	27.75	28.56	26.89	27.73	40.75	41.96	39.93	40.88	37.92	38.98	36.80	37.90	43.70	45.00	42.89	43.86	40.51	41.69	39.27	40.49	
	Z ₂	29.49	30.20	28.81	29.50	27.45	28.14	26.79	27.46	40.41	41.45	39.80	40.55	37.53	38.44	36.67	37.55	43.35	44.47	42.76	43.53	40.08	41.09	39.11	40.09																											
N	Z ₁	31.65	32.04	31.27	31.65	29.26	29.64	28.88	29.26	43.58	44.24	43.25	43.69	40.30	40.79	39.80	40.30	46.62	47.40	46.38	46.80	42.72	43.27	42.17	42.72	Control	Z ₁	31.46	31.86	31.16	31.49	29.07	29.46	28.78	29.10	43.40	44.03	43.04	43.49	40.05	40.56	39.66	40.09	46.43	47.17	46.16	46.59	42.44	43.01	42.02	42.49	
	Z ₂	29.76	30.42	29.27		27.32	27.96	26.85		40.85	41.86	40.28		37.88	38.73	37.26		43.78	44.89	43.26		40.34	41.29	39.64																												
		MxN			M	MxN			M	MxN			M	MxN			M	MxN			M	MxN					MxN			M	MxN			M	MxN																	
M	M ₁	29.84	30.79	29.45	30.03	27.19	28.12	26.82	27.38	40.85	42.26	40.52	41.21	37.98	39.20	37.49	38.22	43.76	45.31	43.51	44.19	40.25	41.62	39.69	40.52	M ₂	M ₂	28.00	28.53	27.57	28.04	25.31	25.83	24.89	25.34	38.48	39.33	37.59	38.46	35.65	36.32	35.10	35.69	41.30	42.22	40.43	41.32	38.22	39.00	37.59	38.27	
	M ₃	29.64	30.41	28.86	29.64	27.60	28.35	26.84	27.60	40.58	41.71	39.87	40.72	37.73	38.71	36.74	37.72	43.52	44.74	42.82	43.69	40.29	41.39	39.19	40.29		M ₄	M ₄	31.56	31.95	31.21	31.57	29.17	29.55	28.83	29.18	43.49	44.13	43.15	43.59	40.17	40.67	39.73	40.19	46.53	47.29	46.27	46.69	42.58	43.14	42.09	42.60
			NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z	NxZ							NxZ			Z	NxZ			Z	NxZ														
	Z	Z ₁	29.92	30.57	29.33	29.94	27.47	28.10	26.90	27.49	41.02	42.04	40.41	41.16	38.09	38.91	37.33	38.11	43.96	45.08	43.40	44.14	40.57	41.50	39.71			40.59	Control	Z ₂	29.60	30.28	29.22	29.70	27.16	27.82	26.79	27.26	40.68	41.67	40.14	40.83	37.68	38.54	37.20	37.80	43.60	44.70	43.12	43.80	40.10	41.08
		S.Em ±			CD at 5 %	S.Em ±			CD at 5 %	S.Em ±			CD at 5 %	S.Em ±			CD at 5 %	S.Em ±			CD at 5 %	S.Em ±						S.Em ±				CD at 5 %	S.Em ±			CD at 5 %	S.Em ±															
		M	0.40	1.39	0.28	0.98	0.58	0.58	2.01	0.38	1.30	0.36	1.23	0.25	0.85	0.85	0.36	1.23	0.25	0.85	0.85	0.36	1.23	0.25	0.85			N	0.25	0.75	0.19	0.58	0.36	1.00	0.28	0.82	0.31	0.94	0.33	0.90	0.33	0.90	0.33	0.90	0.33	0.90	0.33	0.90	0.33	0.90		
		Z	0.26	NS	0.29	NS	0.40	NS	0.35	NS	0.43	NS	0.38	NS	0.35	NS	0.43	NS	0.38	NS	0.35	NS	0.43	NS	0.38	NS			M x N	0.50	NS	0.39	NS	0.72	NS	0.76	NS	0.63	NS	0.85	NS	0.76	NS	0.66	NS	0.76	NS	0.66	NS	0.76	NS	
		M x Z	0.53	NS	0.58	NS	0.80	NS	0.70	NS	0.85	NS	0.74	NS	0.60	NS	0.74	NS	0.66	NS	0.74	NS	0.66	NS	0.74	NS			N x Z	0.46	NS	0.50	NS	0.69	NS	0.60	NS	0.74	NS	0.66	NS	0.74	NS	0.66	NS	0.74	NS	0.66	NS	0.74	NS	
		M x N x Z	0.92	NS	1.01	NS	1.38	NS	1.21	NS	1.47	NS	1.32	NS	1.32	NS	1.47	NS	1.32	NS	1.32	NS	1.47	NS	1.32	NS			Control vs Rest	1.47	2.55	1.04	1.79	2.13	3.69	1.38	2.39	1.31	2.27	0.90	1.56	0.90	1.56	0.90	1.56	0.90	1.56	0.90	1.56	0.90	1.56	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)
 Sub plot : Foliar spray of nano nitrogen (N)
 Sub-sub plot : Foliar spray of nano zinc (Z)

M₁ : 100 % RDF (ZnSO₄·7H₂O @ 25 kg ha⁻¹)
 N₁ : FS of nano N @ 2000 ppm
 Z₁ : FS of nano Zn @ 2000 ppm

M₂ : 75 % RDN
 N₂ : FS of nano N @ 4000 ppm
 Z₂ : FS of nano Zn @ 3000 ppm

M₃ : 100 % RDN
 N₃ : FS of nano N @ 6000 ppm

M₄ : 125 % RDN

Table 6. Normalized Difference Vegetation Index (NDVI) at active tillering, panicle initiation and flowering stages of paddy as influenced by different levels of nitrogen along with foliar application of nano nitrogen and nano zinc

MxNxZ	Active tillering								Panicle initiation								Flowering								
	Rabi (Pooled 2021 and 2022)				Kharif -2021				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	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	
M ₁	Z ₁	0.51	0.53	0.49	0.51	0.47	0.49	0.45	0.47	0.69	0.73	0.66	0.69	0.63	0.67	0.61	0.63	0.81	0.84	0.78	0.81	0.75	0.79	0.72	0.75
	Z ₂	0.49	0.52	0.48	0.50	0.45	0.48	0.45	0.46	0.67	0.70	0.65	0.67	0.61	0.64	0.60	0.62	0.79	0.82	0.77	0.80	0.73	0.76	0.71	0.74
M ₂	Z ₁	0.42	0.43	0.40	0.42	0.38	0.39	0.37	0.38	0.59	0.61	0.57	0.59	0.51	0.54	0.50	0.52	0.73	0.76	0.73	0.74	0.62	0.64	0.60	0.62
	Z ₂	0.41	0.43	0.39	0.41	0.37	0.39	0.36	0.37	0.58	0.60	0.56	0.58	0.50	0.53	0.49	0.51	0.72	0.75	0.71	0.73	0.61	0.64	0.59	0.61
M ₃	Z ₁	0.47	0.48	0.46	0.47	0.43	0.44	0.42	0.43	0.65	0.67	0.64	0.65	0.58	0.60	0.57	0.59	0.77	0.82	0.75	0.78	0.70	0.71	0.68	0.70
	Z ₂	0.46	0.47	0.46	0.46	0.42	0.43	0.42	0.42	0.63	0.65	0.64	0.64	0.57	0.58	0.58	0.58	0.78	0.77	0.74	0.77	0.67	0.70	0.67	0.68
M ₄	Z ₁	0.54	0.56	0.52	0.54	0.49	0.52	0.48	0.50	0.73	0.76	0.70	0.73	0.68	0.71	0.66	0.68	0.86	0.88	0.85	0.86	0.82	0.86	0.80	0.83
	Z ₂	0.53	0.55	0.51	0.53	0.49	0.51	0.47	0.49	0.72	0.74	0.69	0.72	0.67	0.70	0.65	0.67	0.84	0.87	0.82	0.84	0.80	0.84	0.78	0.81
N		0.47	0.50	0.46	0.44	0.46	0.43	0.46	0.65	0.68	0.64	0.65	0.62	0.59	0.62	0.58	0.78	0.81	0.76	0.78	0.70	0.74	0.68	0.68	0.68
		MxN			M			MxN			M			MxN			M			MxN			M		
M	M ₁	0.50	0.52	0.48	0.50	0.46	0.48	0.45	0.46	0.68	0.72	0.65	0.68	0.62	0.65	0.60	0.63	0.80	0.83	0.78	0.80	0.74	0.78	0.72	0.75
	M ₂	0.41	0.43	0.40	0.41	0.38	0.39	0.37	0.38	0.58	0.60	0.57	0.58	0.51	0.53	0.50	0.51	0.73	0.75	0.72	0.73	0.61	0.64	0.60	0.62
	M ₃	0.46	0.48	0.46	0.47	0.42	0.43	0.42	0.43	0.64	0.66	0.64	0.65	0.58	0.59	0.57	0.58	0.77	0.79	0.75	0.77	0.69	0.70	0.68	0.69
	M ₄	0.53	0.55	0.51	0.53	0.49	0.51	0.48	0.49	0.72	0.75	0.70	0.72	0.67	0.70	0.65	0.68	0.85	0.88	0.83	0.85	0.82	0.85	0.79	0.82
		NxZ			Z			NxZ			Z			NxZ			Z			NxZ			Z		
Z	Z ₁	0.48	0.50	0.47	0.48	0.44	0.46	0.43	0.44	0.66	0.69	0.64	0.67	0.60	0.63	0.58	0.60	0.79	0.82	0.78	0.80	0.72	0.75	0.70	0.72
	Z ₂	0.47	0.49	0.46	0.47	0.43	0.45	0.43	0.44	0.65	0.67	0.64	0.65	0.59	0.61	0.58	0.59	0.79	0.80	0.76	0.78	0.70	0.73	0.69	0.71
Control		0.28				0.26				0.43				0.36				0.57				0.51			
		S.Em ±			CD at 5 %			S.Em ±			CD at 5 %			S.Em ±			CD at 5 %			S.Em ±			CD at 5 %		
M		0.01			0.02			0.01			0.02			0.01			0.02			0.01			0.03		
N		0.01			0.02			0.00			0.01			0.02			0.01			0.03			0.01		
Z		0.00			NS			NS			NS			NS			NS			NS			NS		
M x N		0.01			NS			0.01			NS			0.02			NS			0.02			NS		
M x Z		0.01			NS			0.01			NS			0.01			NS			0.01			NS		
N x Z		0.01			NS			0.01			NS			0.01			NS			0.01			NS		
M x N x Z		0.02			NS			0.01			NS			0.02			NS			0.02			NS		
Control vs rest		0.02			0.03			0.02			0.04			0.03			0.05			0.02			0.03		

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)

Sub plot : Foliar spray of nano nitrogen (N)

Sub-sub plot : Foliar spray of nano zinc (Z)

M₁ : 100 % RDF (ZnSO₄.7H₂O @ 25 kg ha⁻¹)

N₁ : FS of nano N @ 2000 ppm

Z₁ : FS of nano Zn @ 2000 ppm

M₂ : 75 % RDN

N₂ : FS of nano N @ 4000 ppm

Z₂ : FS of nano Zn @ 3000 ppm

M₃ : 100 % RDN

N₃ : FS of nano N @ 6000 ppm

M₄ : 125 % RDN

Table 7. 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			
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			
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)

Sub plot : Foliar spray of nano nitrogen (N)

Sub-sub plot : Foliar spray of nano zinc (Z)

M₁ : 100 % RDF (ZnSO₄.7H₂O @ 25 kg ha⁻¹)

N₁ : FS of nano N @ 2000 ppm

Z₁ : FS of nano Zn @ 2000 ppm

M₂ : 75 % RDN

N₂ : FS of nano N @ 4000 ppm

Z₂ : FS of nano Zn @ 3000 ppm

M₃ : 100 % RDN

N₃ : FS of nano N @ 6000 ppm

M₄ : 125 % RDN

Interaction effect among different levels of nitrogen, FS of nano N and FS of nano Zn showed non-significant difference but the higher NDVI values were recorded with the combination of 125 per cent RDN along with FS of nano N @ 4000 ppm and nano Zn @ 2000 ppm (0.56, 0.76 & 0.88 and 0.52, 0.71 & 0.86 during *rabi* and *kharif* season, respectively) while, lower NDVI values was recorded with the combination of 75 per cent RDN along with FS of nano N @ 6000 ppm and nano Zn @ 3000 ppm (0.40, 0.56 & 0.71 and 0.36, 0.49 & 0.59 during *rabi* and *kharif* season, respectively) at AT, PI and FS of paddy crop.

NDVI values indicate the extent of canopy coverage and healthy status of plants indirectly suggesting good photosynthetic area. Application of nitrogen fertilizer may enhance the photosynthetic light capture in leaf blades, possibly increasing turf growth and quality under reduced light conditions [29]. Canopy/vegetation coverage and healthy status of plants are determined by the extent of green leaf area covering the ground. In the present study the higher NDVI associated with $M_4N_2Z_1$, was due to higher leaf area and LAI of that treatment.

3.6 Yield of Paddy (kg ha⁻¹)

Grain and straw yield differed significantly between different levels of nitrogen and foliar spray of nano N (Table 7 above). 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 was on par with 100 per cent RDN with $ZnSO_4 \cdot 7H_2O$ @ 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.

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 6581 kg 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 (2000). 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 [16]. 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 effect of zinc which helps in increasing enzymatic activity. Muthukumararaja & Sriramachandrasekharan [30] 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 [31-33].

4. CONCLUSIONS

Spraying of liquid nano nitrogen and nano zinc has increased paddy crop yield by increasing plant growth parameters. Spraying of nano nitrogen and nano zinc proved to be beneficial particularly under transplanted conditions. This also led to saving of mineral N in the form of nitrogen fertilizer thereby decreased the accumulation of N in the soil. 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. 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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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