Effect of nano nitrogen and nano zinc on growthand yield of paddy in paddy-paddy cropping system

ABSTRACT

An investigation on nano nitrogen and nano zinc with different levels of nitrogen approaches on growthand 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-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 RDN has recorded significantly taller plants (97.11 and 96.54 cm), higher number of tillers hill^{-1} (19.65 and18.14) and total dry matter (70.06 and 64.54 g hill^{-1}) at harvest stage of crop and SPAD values (46.69 and42.60) andNDVI values (0.85 and0.82) at flowering stage of crop, Similarly, foliar spray of nitrogen @ 4000ppm has recorded significantly higher plant height (95.44 and91.33 cm), higher number of tillers hill^{-1} (17.75 and 16.01), total dry matter (66.84 and62.31 g hill^{-1}) SPAD values at flowering stage (44.89 and41.29), NDVI values at flowering stage (0.81 and 0.74), grain yield (5623 & and 6840 kg ha^{-1}) and straw yield (5352 and6581 kg ha^{-1}). Interaction effect showed non- significant effect with different combination treatments.

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

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 (Directorate of Economics and Statistics, 2011). 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(Sureka*et al*., 2003).

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

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Reference style

References must be listed at the end of the manuscript and numbered in the order that they appear in the text. Every reference referred in the text must also present in the reference list and vice versa. In the text, citations should be indicated by the reference number in brackets [3].

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 factors to be considered for nitrogen (N) management. Since nitrogen 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 nitrogen availability be sustained during the crop period.

Nowadays, application of nano particles 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 (Giraldo*etal*., 2014). 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 (DeRosa *et al.*, 2010). Nanotechnology has potential to develop slow release efficient fertilizers (Sharma, 2008) 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 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 IFFCO Ltd. These products have been researched and developed indigenously at the IFFCO Nano Biotechnology

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Since N fertilization ....

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....by Experience Indian Farmers Fertiliser Cooperative Limited (IFFCO Ltd).

Research Centre (NBRC) at Kalol Unit, Gujarat. Nano nitrogen contains 4% of N and nano zinc contains 1% of Zn.

Treatment details

Experimental site and soil

The field experiments were conducted in Krishi Vigyana Kendra, Gangavathi (Dist: Koppal) during *rabi* season of 2020-2021 and *kharifand 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 (Telengana Sona). It has unique grain size, short slender, 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* season.

Experimental details

The experiment was laid out in a split-split plot design with twenty four treatments and three replications. The main-plot consisted of different nitrogen levels (100% RDN + $ZnSO_4.7H_2O$ @ 25 kg ha^{-1}, 75% RDN, 100 % RDN and 125% RDN), sub-plots were applied with threelevels of nano nitrogen [2000 ppm (2 ml L^{-1}), 4000 ppm (4 ml L^{-1}) and 6000 ppm (6 ml L^{-1})] and sub-sub plots with two levels of nano zinc [2000 ppm (2 ml L^{-1}) and 3000 ppm (3 ml L^{-1})].The details of treatment shown in Table 1.

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)

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MATERIALS AND METHODS
Experimental site and soil characteristics
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Comment [E15]: ....medium electrical conductivity (EC) (1.26dS m-1) and high in organic carbon (OC) (7.01 g kg-1).

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Experimental details
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Comment [E18]: 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.

Table 1. Treatment details

M1: 100 % RDF ($ZnSO_4.7H_2O$ @ 25 kg ha^{-1}) **M2**: 75 % RDN **M3**: 100 % RDN **M4**: 125 % RDN	**N1**:FS of nano N @ 2000 ppm (2 ml L^{-1}) **N2**: FS of nano N @ 4000 ppm (4 ml L^{-1}) **N3**: FS of nano N @ 6000 ppm (6 ml L^{-1})	**Z1**:FS of nano Zn @ 2000 ppm (2 ml L^{-1}) **Z2**:FS of nano Zn @ 3000 ppm (3 ml L^{-1})

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Recommended dose of P & K was ~~ere~~ 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.

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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. 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}).

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Normalized Difference Vegetation Index (NDVI)

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 (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

The data on growth, yield and nutrient uptake paddy are furnished 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 ~~ere~~ similar. Hence, only pooled data of the *rabi* season and one year data of *kharif* season are used to emphasize the results.

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Plant height (cm) of paddy

Among different nitrogen levels, 125 per cent RDN (M_4) recorded higher plant height at panicle initation (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 heightat PI and HS of paddy crop (65.19&80.40 and63.99 &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 & 87.81and 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 andrecorded higher in 125 per cent RDN (M_4) followed by 100 per cent RDF with $ZnSO_4.7H_2O$ 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.* (2007) 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 zincwhich accelerate the activity of enzyme and auxin metabolism in the plant, which in turn enlarge the cell andcellelongation mightresultedintallerplants.Thisisinconformitywiththeworks of Torres-Olivar*et al.* (2014) and Nithya*et al.* (2018).Benzon*et al*. (2015) 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.

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 &16.01during *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 & 14.95at 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 lowernumber of tillers hill^{-1}at PI and FS of paddy crop (9.42 &11.24and9.80 & 11.37during *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 probablyduetoincreasedsupplyof nitrogen andzinctoplants,whichhaveacceleratedtheactivityofenzymes involvedinphotosynthesis,carbohydratesmetabolism,proteinsynthesis,celldivisionandcellelongation. Thisisinconformitywiththework of Beeresha (2018) and Uma (2019). Wijebandara (2007) reported that the availability of required quantity of N for long time was probably responsible for producing a greater ~~more~~ 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 (2013) who reported that increased number of tillers per hill could be expected up to 40 % N in excess of RDF N. Manzoor *et al.* (2006), Wijebandara (2007) and Choudhary and Pandey (2009) also reported similar observations.

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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.* (2000) 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.* (2006) and Wijebandara (2007). Nano-fertilizers induced nitrate reductase and increased activity of chloroplast (Hong *et al*., 2005), rubisco (Gao *et al*., 2006) and antioxidant enzyme system (Nekrasova *et al*., 2011) that might be the possible underlying mechanism for enhanced growth and increase in number of tillers.

Total dry matter production per hill (ghill^{-1})~~**(Table 7)**~~

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 ghill^{-1} during *rabi* and *kharif* season, respectively) followed by 100 per cent RDF +$ZnSO_4.7H_2O$ @ 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 ghill^{-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& 60.29ghill^{-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& 67.41ghill^{-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 ghill^{-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&47.25ghill^{-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, number of tillers and leaf area with dry matter production. The treatment with 125 per cent RDN (M_4) was associated with increased plant height, number of tillers and leaf area index. Higher leaf area index helps in better utilization of solar radiation and available nutrients which are essential for higher dry matter accumulation

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.* (2013), Mahmoodzadeh*et al.* (2013), Kumar *et al.* (2014), Benzon*et al.* (2015), Hafeez *et al.* (2015) and Aziz *et al*. (2016).

Chlorophyll content (Table 8)

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. 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*

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Leaf area index?
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Estimated chlorophyll content (SPAD values)

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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 valuesat AT, PI and FS of paddy crop (24.83, 31.06 &35.14 and 24.86, 29.38 &33.44during *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 (Farnia and Omidi, 2015). 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.* (2015). 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 (Balashouri and Prameeladevi, 1995).

Normalized Difference Vegetation Index (NDVI) ~~(Table 9)~~

The data pertaining to NDVI differed significantly among different nitrogen levels and FS of nano N. 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 M_1, M_3 and M_2. Similarly significant higher NDVI values were recorded in different stages of paddy crop by FS of nano N @ 4000 ppm

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(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 valuesat AT, PI and FS of paddy crop (0.28, 0.43&0.57, and 0.26, 0.36&0.51during *rabi* and *kharif* season, respectively).

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 (Trenholm *et al.*, 2004). 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 NDVIassociated with $M_4N_2Z_1$, was due to higher leaf area and LAI of that treatment.

Yield of paddy(kg ha^{-1})

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

Comment [E33]: ...of nano N (Table 7).

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 (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 (Choudhary and Pandey, 2009). 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 (2012) 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.

Conclusions

Spraying of liquid nano nitrogen and nano zinc has increased 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

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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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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)**	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: Number of tillers per hill at panicle initiation and harvestof 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 %	
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)**	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: Total dry matter production (g hill^{-1}) at flowering and harvest stages of paddy as influenced by different levels of nitrogen along with foliar sprayof 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	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	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)** 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: 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				*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	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**
	Z_2	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**
M_2	Z_1	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**
	Z_2	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_3	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**
M_4	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**
	Z_2	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**
N		**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			M
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	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	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			Z
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**
	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	39.57	**40.25**
Control		25.07				24.86				31.06				29.38				35.14				33.44			
		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 ±		CD at 5 %	
M		0.40		1.39		0.28		0.98		0.58		2.01		0.38		1.30		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	
Z		0.26		NS		0.29		NS		0.40		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	
M x Z		0.53		NS		0.58		NS		0.80		NS		0.70		NS		0.85		NS		0.76		NS	
N x Z		0.46		NS		0.50		NS		0.69		NS		0.60		NS		0.74		NS		0.66		NS	
M x N x Z		0.92		NS		1.01		NS		1.38		NS		1.21		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	

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: 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**		**0.65**	**0.68**	**0.64**		**0.59**	**0.62**	**0.58**		**0.78**	**0.81**	**0.76**		**0.70**	**0.74**	**0.68**	
		MxN			M	MxN			M	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	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 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M		0.01		0.02		0.01		0.02		0.01		0.03		0.00		0.02		0.01		0.02		0.01		0.03	
N		0.01		0.02		0.00		0.01		0.01		0.02		0.01		0.02		0.01		0.03		0.01		0.03	
Z		0.00		NS		0.00		NS		0.01		NS		0.01		NS		0.01		NS		0.01		NS	
M x N		0.01		NS		0.01		NS		0.02		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		0.01		NS		0.01		NS	
N x Z		0.01		NS		0.01		NS		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		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		0.02		0.04		0.03		0.05	

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: 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**			

	Grain *Rabi* S.Em ±	Grain *Rabi* CD at 5 %	Grain *Kharif* S.Em ±	Grain *Kharif* CD at 5 %	Straw *Rabi* S.Em ±	Straw *Rabi* CD at 5 %	Straw *Kharif* S.Em ±	Straw *Kharif* 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