

Effect of nano nitrogen and nano zinc on soil fertility and crop productivity of paddy-paddy cropping system

Abstract:

Field experiments were conducted during *rabi* and *kharif* seasons of 2020-21 and 2021-22 at Krishi Vigyana Kendra, Gangavathi, Koppal, Karnataka, India, to study the influence of nano nitrogen and nano zinc on soil fertility and crop productivity of paddy-paddy cropping system. The experiment was laid out in split-split plot design with different levels of nitrogen in main plots, nano nitrogen sprays in sub-plots and nano zinc sprays in sub-sub plots which were replicated thrice. The results of the study indicated that application of 125 per cent RDN along with foliar spray of nitrogen @ 4000 ppm and nano Zn @ 2000 ppm has recorded significantly higher grain yield, straw yield, soil available N, P₂O₅, K₂O, S and Zn during both *rabi* and *kharif* season and which was on par with and 100 per cent RDN along with spray of nano nitrogen @ 4000 ppm and nano Zn @ 2000 ppm. Hence for effective management of nano fertilizers in paddy, the application of 100 per cent RDN along with foliar spray of nano N @ 4000 ppm and foliar spray of nano Zn @ 2000 ppm was recommended.

Key words: Crop productivity, Soil fertility, Nano nitrogen, Nano zinc and Foliar spray

Introduction

The use of fertilizer is being practiced to produce enough food for increasing population. However, the fertilizers, particularly nitrogen (N) being used in many fold excess due to their low use efficiency and availability in the preferred chemical form, uptake by plants. The typical use efficiency of nitrogen fertilizer (urea) is about 30–40% and phosphate is about 15–20% in most agriculture settings. The unutilized fertilizer input release to the environment and pollute soil, air, water. For instance, urea volatilize in the form of nitrous oxide, a greenhouse gas and emit in the form of ammonia contributing to the global warming and air pollution (Liu *et al.*, 2013). The leached urea in form of nitrate through soil affecting the drinking water quality. Moreover, use of urea affect the soil pH that further affect the uptake efficiency of essential macro and micro nutrient by the plants. Soil fertilization with Zn is necessary in Zn-deficient soils because the lack of sufficient Zn early in the crop development may predispose plants to grain yield losses and later fertilization will not alleviate. However the efficiency of applied zinc is around less than 5 per cent, as which there is a need to improve the efficiency of applied Zinc. While, foliar fertilization is an effective way of increasing Zn concentration in the grain as Zn is relatively easily transported in the phloem. To improve the nutrient use efficiency, alternative smart agri-inputs based on the concepts of advanced chemical engineering, biotechnology, microbiology, polymer science are being developed for the control and slow release of nutrient in the soil (Keating *et al.* 2010). However, success is limited due to varying agro-climatic conditions, plant and food demand diversity and soil nutrient profiles. World population is expected to grow over 10 billion by 2100 and Asia is the top continent by population, hence the food demand is more.

Comment [D1]: affects

Comment [D2]: affects

Comment [D3]: remove comma

Therefore, it is important to develop and adopt sustainable practices wherein adequate food can be produced while minimizing the environmental impact of less efficient fertilizers.

Since last two decades, nanotechnology is being explored to enhance the nutrient use efficiency and target delivery of nutrients to plants. Fertilizers made at nanoscale (1–100 nm) having higher surface area to volume size ratio and feature of surface functionalization along with slow or plant response based release (Raliya, *et al.*, 2017). For instance, zinc oxide nanofertilizers were used to mobilize native phosphorus in soil in addition to fertilize the zinc itself. Similarly, urea coated with hydroxyapatite was tested on rice crop with the aim to reduce the bulk use of alternative nitrogen (Kottegoda, *et al.*, 2017). The interesting observation evidenced from the laboratory or small scale field trials of nanotechnology based fertilizer inputs was the reduction in the demand of conventional bulk alternatives while maintaining or increasing the crop productivity. This inspires the present study to investigate the influence of nanofertilizers of nitrogen and zinc along with different levels of conventional nitrogen fertilizer is being practiced. The nanofertilizers were used to reduce the imbalanced use of bulk fertilizer such as urea with a larger aim to demonstrate alternative practice for sustainable and precision agriculture.

Comment [D4]: Italic

Comment [D5]: remove comma

Material and methods

The field experiments were conducted in Krishi Vigyana Kendra, Gangavathi (Dist: Koppal) during *rabi* season of 2020-2021 and *kharif* and *rabi* season 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 EC (1.26 dS m⁻¹) and high in OC (7.01 g kg⁻¹). The soil was low in available nitrogen (191.25 kg 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) and it can be cultivated during both *kharif* and *rabi* season.

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

Table 1: Treatment details

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

Analysis of soil properties

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

Yield measurement

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

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).

Result and discussion

There was a slight difference in crop yield, soil available P₂O₅, K₂O, S and micronutrients (Zn, Fe, Cu and Mn) during both *kharif* and *rabi* experiments, but the pattern of response were similar. Hence, only pooled data of the *rabi* season and one year data of *kharif* season are used to emphasize the results.

Productivity of paddy-paddy cropping system (Table 2)

Grain and straw yield differed significantly between different levels of nitrogen and foliar spray of nano N. Among the different levels of nitrogen, addition of 125 per cent RDN (M₄) 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 ZnSO₄.7H₂O @ 25 kg ha⁻¹ (M₁: 5485 & 5217 kg ha⁻¹ and 6690 & 6417 kg ha⁻¹) and 100 per cent RDN (M₃: 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 (M₂: 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 (N₂: 5623

&5352 kg ha⁻¹ and 6840 and 6581kg ha⁻¹) followed by foliar spray of nano N @ 2000 ppm (N₁: 5359 & 5101 kg ha⁻¹ and 6522 and 6273 kg ha⁻¹) and foliar spray of nano N @ 6000 ppm (N₃: 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 (Z₁) and was on par with the Z₂ (foliar spray of nano N @ 3000 ppm: 5384 & 5124 kg ha⁻¹ and 6551 & 6302 kg ha⁻¹during *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 M₄ 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.

Soil fertility

Among different nitrogen levels (Table 3 to 7), 125 per cent RDN (M₄) recorded higher soil available nitrogen (M₄: 241.65 & 222.40 and 262.38 & 233.23 kg ha⁻¹), P₂O₅ (58.00 & 42.69 and 61.05 & 49.16 kg ha⁻¹), K₂O (366.33 & 326.68 and 370.90 & 331.90 kg ha⁻¹) and S (21.38 & 16.97 and 21.87 & 17.81 mg kg⁻¹), however, higher DTPA-Zn recorded with 100 per cent RDN with ZnSO₄.7H₂O at 25 kg ha⁻¹ (1.20 & 1.11 and 1.26 & 1.17 mg kg⁻¹) at panicle initiation (PI) and harvest stage (HS) of paddy crop (82.09 & 97.11 and 78.51 & 96.54 cm during *rabi* and *kharif* season, respectively) as compared to other treatments of different nitrogen levels (Table 2). Similarly, significant higher soil available nitrogen was recorded by foliar spray of nano N @ 4000 ppm (N₂: 225.61 & 206.36 and 242.82 & 212.57 kg ha⁻¹), P₂O₅ (56.74 & 41.23 and 59.36 & 47.56 kg ha⁻¹), K₂O (354.20 & 314.55 and 358.77m& 319.77 kg ha⁻¹), S (19.34 & 15.94 and 20.24 & 15.74 mg kg⁻¹) and Zn (1.16 & 1.07 and 1.22 & 1.13 mg kg⁻¹) at panicle initiation (PI)&harvest stage (HS)of paddy crop during *rabi* and *kharif* season, respectively, followed by FS of nano N @ 2000 ppm (N₁) and 6000 ppm (N₃).The treatment, foliar spray of nano Zn @ 2000 ppm (Z₁: 157.44 and 141.44 kg ha⁻¹) recorded maximum soil available N, P₂O₅, K₂O, S and Zn, but non-significant and was on par with the foliar spray of nano Zn @ 3000 ppm during *rabi* and *kharif* season, respectively. Whereas, minimum soil available N, P₂O₅, K₂O, S and Zn was recorded in absolute control.

Comment [D6]: correct spell

Comment [D7]: correct spelling

As far as the interaction effect, it is evident from the data that total N uptake by paddy showed non-significant difference but the higher soil available N (246.90 & 227.65 and 274.78 & 244.24 kg ha⁻¹), P₂O₅ (55.41 & 40.20 and 58.31 & 46.56 kg ha⁻¹), K₂O (344.22, &304.57 and 348.80 & 309.80 kg ha⁻¹), S (18.85 & 15.46 and 19.70 & 15.37 mg kg⁻¹) and Zn (1.25 & 1.16 and 1.31 & 1.22 mg kg⁻¹) was recorded with the combination of 125 per cent RDN along with FS of nano N @ 4000 ppm and nano Zn @ 2000 ppm. While, lower soil available N (188.55 & 169.30 and 195.74 & 162.03 kg ha⁻¹), P₂O₅ (49.37 & 34.73 and 52.14, & 40.72 kg ha⁻¹), K₂O (304.66 & 265.01 and 309.24 & 270.24 kg ha⁻¹) and S (15.01 & 12.54 and 16.31 & 11.74 mg kg⁻¹) during *rabi* and *kharif* season, respectively, was recorded with the combination of 75 per cent RDN along with FS of nano N @ 6000 ppm and nano Zn @ 3000 ppm.

Soil available N, P₂O₅, K₂O, S and Zn showed decreasing trend from panicle imitiation stage to harvest stage of paddy under different levels of soil N, FS nano N and FS nano Zn studied which may be attributed to the continuous absorption of P₂O₅, K₂O, S and Zn by crop with increasing biomass as the crop growth stage advances. The significant increase in available N content might be due to synergistic interaction between zinc and nitrogen. This increase in available N was due to fertilizer application to treatment plots. Similar results were obtained by Ramrao (2021) in paddy by application of nanoZn. Potassium use efficiency was increased in wheat crop by integrated use of nano and non-nano fertilizers *i.e.*, nano 100 % NPK + Nano NPK sprays at 20, 30 and 45 DAS @ 3 ml litre⁻¹ of water + 2 Nano-K sprays at grain development stage @ 4 ml litre⁻¹ of water 115 and 125 DAS, Swati and Rajeev (2019). Application of nano nitrogen chelated fertilizer (NNC) had significant effect on reducing nitrate leaching and increasing sugar production in sugarcane and NUE (Mahmoud *et al.*, 2020). Application of nano N and Zn increased the availability of sulphur in the soil. This may be due to synergistic effect of nitrogen and zinc on sulphur which might have enhanced the availability of sulphur for the plant growth. These results corroborate with the findings of Singh and Kumar (2017) in sunflower by foliar spray of 500 ppm nanoZnS.

Comment [D8]: correct spell

Conclusion

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

Comment [D9]: correct spell

References

- Bhowmick, N. and Nayak, R. L., 2000, Response of hybrid rice (*Oryza sativa*) varieties to nitrogen, phosphorus and potassium fertilizers during dry (boro) season in West Bengal. *Indian J. Agron.*, 45(2): 323-326.
- Choudhary, S. K and Pandey, D. N., 2009, Response of rice genotypes to levels of nitrogen in low land. *Oryza*, 46(1): 42-44.
- Duan, Y. *et al.* Nitrogen use efficiency in a wheat–corn cropping system from 15 years of manure and fertilizer applications. *Field Crop Res.* 157, 47–56 (2014).
- Gomez, K. A. and Gomez, A. A., 1984, Statistical procedures for agricultural research. 2nd Ed. *John Wiley Sons*, New York.
- Keating, B. A. *et al.* Eco-efficient agriculture: Concepts, challenges, and opportunities. *Crop Sci.* 50, S109–S119 (2010).
- Kottegoda, N. *et al.* Urea-hydroxyapatite nanohybrids for slow release of nitrogen. *ACS Nano* 11, 1214–1221 (2017).
- Liu, X. *et al.* Enhanced nitrogen deposition over China. *Nature* 494, 459–462 (2013).
- Mahmoud, A., Ebrahim, P. and Abdali, N., 2020, Assessing the effects of urea and nano-nitrogen chelate fertilizers. *Soil Sci. Plant Nutrition.*, pp. 1-8.
- Muthukumararaja, T. M. and Sriramachandrasekharan, M. V., 2012, Effect of zinc on yield, zinc nutrition and zinc use efficiency of lowland rice. *J. Agric. Technol.*, 8(2): 551-561.
- Raliya, R. *et al.* Nanofertilizer for precision and sustainable agriculture: Current state and future perspectives. *J. Agric. Food Chem.* 66, 6487–6503 (2017).
- Ramarao, 2021, Studies on foliar application of nano zinc and silicon on performance of paddy under different establishment methods. *Ph.D. Thesis*, Univ. Agric. Sci., Raichur.
- Singh, M. D. and Kumar, B. A., 2017, Bio efficacy of nano zinc sulphide (ZnS) on growth and yield of sunflower (*Helianthus annuus* L.) and nutrient status in the soil. *Int. J. Agric. Sci.*, 9(6): 3795-3798.
- Swati, M. and Rajeev, B., 2019, Effect of integrated use of nano and non nanofertilizers on yield and yield attributes of Wheat (*Triticumaestivum* L.). *Int. J. Curr. Microbiol. App. Sci.*, 8(12): 598-606.

Comment [D10]: not mentioned in the manuscript anywhere

Comment [D11]: report names of all authors in all such references

Comment [D12]: write "year" as per standard

UNDER PEER REVIEW

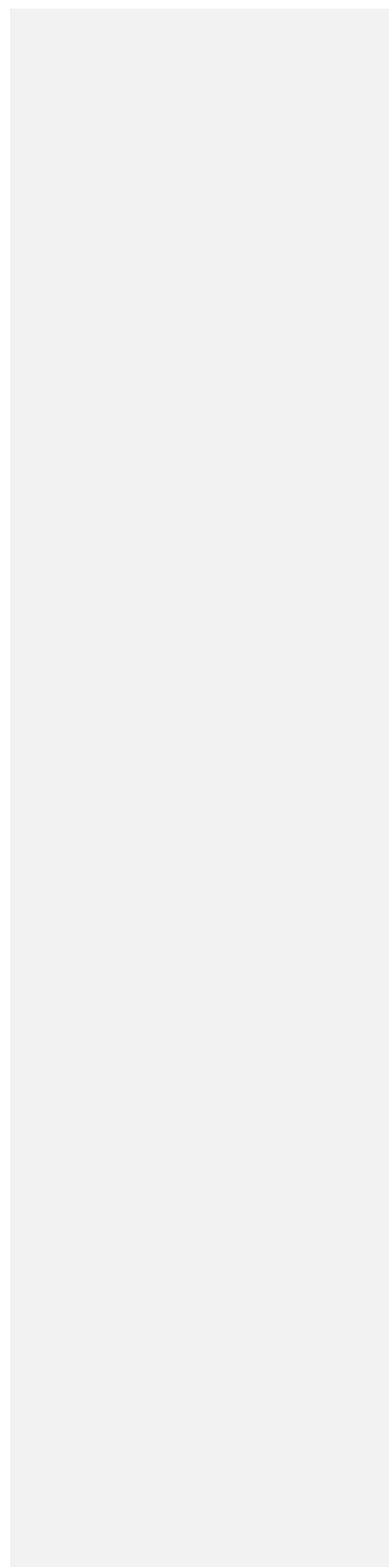


Table 2: Grain yield and straw yield of paddy as influenced by different levels of nitrogen with foliar spray of nano nitrogen and nano zinc during *rabi*(pooled 2021 and 2022)and*kharif*(2021)

MxNxZ		Grain yield (kg ha ⁻¹)								Straw yield (kg ha ⁻¹)							
		<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021				<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021			
		N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ
M ₁	Z ₁	5480	5743	5377	5533	5213	5463	5115	5264	6684	7003	6559	6749	6412	6720	6292	6474
	Z ₂	5352	5604	5352	5436	5091	5331	5091	5171	6529	6834	6528	6630	6262	6557	6262	6360
M ₂	Z ₁	5246	5380	5137	5254	4979	5107	4877	4988	6400	6563	6269	6411	6175	6333	6047	6185
	Z ₂	5191	5234	5051	5159	4927	4969	4794	4897	6334	6386	6164	6295	6110	6161	5945	6072
M ₃	Z ₁	5375	5716	5188	5426	5113	5437	4935	5162	6557	6969	6330	6619	6290	6688	6070	6349
	Z ₂	5234	5622	5118	5325	4979	5348	4868	5065	6386	6856	6245	6496	6124	6578	5988	6230
M ₄	Z ₁	5580	5856	5670	5702	5330	5594	5416	5447	6742	7074	6850	6889	6503	6824	6608	6645
	Z ₂	5417	5825	5604	5615	5174	5564	5353	5364	6544	7037	6770	6784	6312	6789	6531	6544
N		5359	5623	5312		5101	5352	5056		6522	6840	6465		6273	6581	6218	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	5416	5674	5364	5485	5152	5397	5103	5217	6606	6918	6544	6690	6337	6638	6277	6417
	M ₂	5218	5307	5094	5206	4953	5038	4836	4942	6367	6475	6217	6353	6142	6247	5996	6129
	M ₃	5305	5669	5153	5375	5046	5393	4901	5113	6472	6913	6288	6557	6207	6633	6029	6290
	M ₄	5499	5841	5637	5659	5252	5579	5385	5405	6643	7056	6810	6836	6408	6807	6569	6595
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	5420	5674	5343	5479	5159	5400	5086	5215	6596	6902	6502	6667	6345	6641	6254	6413
	Z ₂	5298	5571	5281	5384	5043	5303	5027	5124	6448	6778	6427	6551	6202	6521	6181	6302
Control		3688				3668				4588				4569			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M		81.53		293.53		82.89		295.35		90.08		311.72		91.25		320.83	
N		58.37		175.00		55.82		167.36		82.76		248.11		68.65		205.83	
Z		51.43		NS		52.28		NS		61.71		NS		63.46		NS	
M x N		116.75		NS		111.65		NS		165.51		NS		137.31		NS	
M x Z		102.86		NS		104.56		NS		123.42		NS		126.92		NS	
N x Z		89.08		NS		90.55		NS		106.88		NS		109.92		NS	
M x N x Z		178.16		NS		181.11		NS		213.77		NS		219.83		NS	
Control vs Rest		262.82		454.74		164.95		285.40		330.98		572.66		192.00		332.20	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)

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

MxNxZ		Panicle initiation								At harvest							
		Rabi (Pooled 2021 and 2022)				Kharif -2021				Rabi (Pooled 2021 and 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	224.60	230.32	222.17	225.69	240.12	248.77	226.92	238.61	205.35	211.07	202.92	206.44	213.44	221.13	201.71	212.09
	Z ₂	221.88	227.63	221.26	223.59	234.48	241.68	223.61	233.26	202.63	208.38	202.01	204.34	208.43	214.83	198.77	207.34
M ₂	Z ₁	197.18	200.10	191.63	196.30	209.99	220.11	199.68	209.93	177.93	180.85	172.38	177.05	173.83	182.20	165.29	173.77
	Z ₂	195.74	198.46	188.55	194.25	202.94	208.53	195.74	202.40	176.49	179.21	169.30	175.00	167.99	172.62	162.03	167.55
M ₃	Z ₁	222.79	229.41	217.01	223.07	233.89	241.63	220.56	232.03	203.54	210.16	197.76	203.82	207.90	214.78	196.05	206.25
	Z ₂	217.92	227.41	214.99	220.11	226.53	240.40	218.75	228.56	198.67	208.16	195.74	200.86	201.36	213.69	194.45	203.16
M ₄	Z ₁	242.67	246.90	239.41	242.99	263.64	274.78	256.81	265.08	223.42	227.65	220.16	223.74	234.35	244.24	228.27	235.62
	Z ₂	240.53	244.66	235.73	240.31	261.71	266.66	250.71	259.69	221.28	225.41	216.48	221.06	232.63	237.04	222.85	230.84
N		220.41	225.61	216.34		234.16	242.82	224.10		201.16	206.36	197.09		204.99	212.57	196.18	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	223.24	228.98	221.71	224.64	237.30	245.23	225.27	235.93	203.99	209.73	202.46	205.39	210.94	217.98	200.24	209.72
	M ₂	196.46	199.28	190.09	195.28	206.47	214.32	197.71	206.17	177.21	180.03	170.84	176.03	170.91	177.41	163.66	170.66
	M ₃	220.35	228.41	216.00	221.59	230.21	241.01	219.66	230.29	201.10	209.16	196.75	202.34	204.63	214.23	195.25	204.70
	M ₄	241.60	245.78	237.57	241.65	262.68	270.72	253.76	262.38	222.35	226.53	218.32	222.40	233.49	240.64	225.56	233.23
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	221.81	226.68	217.55	222.02	236.91	246.32	225.99	236.41	202.56	207.43	198.30	202.77	207.38	215.59	197.83	206.93
	Z ₂	219.02	224.54	215.13	219.56	231.42	239.32	222.20	230.98	199.77	205.29	195.88	200.31	202.60	209.54	194.52	202.22
Control		98.75				98.75				74.04				65.59			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M (MP)		2.66		9.20		3.27		11.33		2.26		7.82		3.05		10.57	
N (SP)		1.89		4.68		2.11		6.33		1.94		4.82		2.01		6.01	
Z (SSP)		2.33		NS		2.60		NS		1.89		NS		2.14		NS	
M x N		3.79		NS		4.22		NS		3.88		NS		4.01		NS	
M x Z		4.67		NS		5.19		NS		3.78		NS		4.29		NS	
N x Z		4.04		NS		4.50		NS		3.27		NS		3.71		NS	
M x N x Z		8.09		NS		8.99		NS		6.55		NS		7.43		NS	
Control vs Rest		9.77		16.91		12.03		20.82		8.31		14.37		11.22		19.42	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M) 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 4: Soil available phosphorus (kg ha⁻¹) at panicle initiation and harvest stages of paddy influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during rabi(pooled 2021 and 2022)andkharif(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	55.14	57.45	53.62	55.41	58.19	60.24	57.00	58.48	40.47	42.06	39.07	40.53	46.58	48.04	45.74	46.79
	Z ₂	54.36	55.94	52.79	54.36	57.33	58.83	56.41	57.52	39.61	40.86	38.41	39.63	45.97	47.04	45.11	46.04
M ₂	Z ₁	52.36	54.98	50.50	52.61	54.43	56.76	53.19	54.79	37.26	39.27	35.58	37.37	43.35	45.21	41.56	43.37
	Z ₂	50.97	52.76	49.37	51.03	53.51	55.38	52.14	53.68	36.15	37.49	34.73	36.12	42.62	44.11	40.72	42.48
M ₃	Z ₁	55.26	57.31	52.87	55.15	58.91	60.01	56.05	58.33	40.28	41.45	37.52	39.75	47.43	48.22	43.93	46.53
	Z ₂	54.19	55.78	51.83	53.93	57.21	57.34	55.51	56.69	37.85	40.37	36.78	38.33	44.04	46.30	42.81	44.38
M ₄	Z ₁	58.27	60.56	56.60	58.48	61.40	63.76	59.78	61.65	42.92	44.75	41.76	43.14	49.62	51.17	47.89	49.56
	Z ₂	57.71	59.13	55.75	57.53	60.66	62.54	58.12	60.44	42.49	43.58	40.63	42.23	49.13	50.36	46.79	48.76
N		54.78	56.74	52.92		57.71	59.36	58.03		39.63	41.23	38.06		46.09	47.56	44.32	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	54.75	56.70	53.21	54.88	57.76	59.54	56.70	58.00	40.04	41.46	38.74	40.08	46.28	47.54	45.43	46.41
	M ₂	51.66	53.87	49.93	51.82	53.97	56.07	52.66	54.24	36.70	38.38	35.15	36.75	42.98	44.66	41.14	42.93
	M ₃	54.72	56.54	52.35	54.54	58.06	58.68	55.78	57.51	39.06	40.91	37.15	39.04	45.74	47.26	43.37	45.46
	M ₄	57.99	59.84	56.18	58.00	61.03	63.15	58.95	61.05	42.71	44.16	41.19	42.69	49.37	50.77	47.34	49.16
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	55.26	57.57	53.40	55.41	58.23	60.19	56.51	58.31	40.23	41.88	38.48	40.20	46.74	48.16	44.78	46.56
	Z ₂	54.31	55.90	52.44	54.21	57.18	58.53	55.54	57.08	39.02	40.57	37.64	39.08	45.44	46.95	43.86	45.42
Control		27.23				27.94				21.02				21.34			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M (MP)		0.41		1.41		0.57		1.98		0.28		0.96		0.73		2.51	
N (SP)		0.45		1.33		0.31		0.94		0.38		1.13		0.52		1.45	
Z (SSP)		0.50		NS		0.56		NS		0.32		NS		0.43		NS	
M x N		0.89		NS		0.63		NS		0.76		NS		1.03		NS	
M x Z		1.00		NS		1.11		NS		0.64		NS		0.86		NS	
N x Z		0.86		NS		0.96		NS		0.55		NS		0.75		NS	
M x N x Z		1.73		NS		1.93		NS		1.11		NS		1.50		NS	
Control vs Rest		1.49		2.58		2.10		3.63		1.02		1.77		2.67		4.61	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)

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 5: Soil available potassium (kg ha⁻¹) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during rabi(pooled 2021 and 2022)andkharif(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	345.90	359.35	325.36	343.54	350.48	363.93	329.94	348.11	306.25	319.70	285.71	303.89	311.48	324.93	290.94	309.11
	Z ₂	337.13	348.32	320.22	335.22	341.70	352.90	324.79	339.80	297.48	308.67	280.57	295.57	302.70	313.90	285.79	300.80
M ₂	Z ₁	326.83	342.57	310.79	326.73	331.40	347.15	315.37	331.31	287.18	302.92	271.14	287.08	292.40	308.15	276.37	292.31
	Z ₂	315.86	324.56	304.66	315.03	320.43	329.13	309.24	319.60	276.21	284.91	265.01	275.38	281.43	290.13	270.24	280.60
M ₃	Z ₁	339.00	351.04	318.27	336.10	343.58	355.62	322.85	340.68	299.35	311.39	278.62	296.45	304.58	316.62	283.85	301.68
	Z ₂	327.55	349.13	315.45	330.71	332.13	353.71	320.03	335.29	287.90	309.48	275.80	291.06	293.13	314.71	281.03	296.29
M ₄	Z ₁	368.29	385.60	357.65	370.51	372.86	390.18	362.22	375.09	328.64	345.95	318.00	330.86	333.86	351.18	323.22	336.09
	Z ₂	365.28	372.99	348.16	362.14	369.86	377.56	352.74	366.72	325.63	333.34	308.51	322.49	330.86	338.56	313.74	327.72
N		340.73	354.20	325.07		345.30	358.77	329.65		301.08	314.55	285.42		306.30	319.77	290.65	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	341.51	353.84	322.79	339.38	346.09	358.41	327.37	343.96	301.86	314.19	283.14	299.73	307.09	319.41	288.37	304.96
	M ₂	321.34	333.56	307.73	320.88	325.92	338.14	312.30	325.45	281.69	293.91	268.08	281.23	286.92	299.14	273.30	286.45
	M ₃	333.28	350.09	316.86	333.41	337.85	354.66	321.44	337.98	293.63	310.44	277.21	293.76	298.85	315.66	282.44	298.98
	M ₄	366.79	379.30	352.91	366.33	371.36	383.87	357.48	370.90	327.14	339.65	313.26	326.68	332.36	344.87	318.48	331.90
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	345.00	359.64	328.02	344.22	349.58	364.22	332.59	348.80	305.35	319.99	288.37	304.57	310.58	325.22	293.59	309.80
	Z ₂	336.45	348.75	322.12	335.78	341.03	353.32	326.70	340.35	296.80	309.10	282.47	296.13	302.03	314.32	287.70	301.35
Control		208.37			208.16			188.60			187.64						
		S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	S.Em ±		CD at 5 %	
M (MP)		4.12		14.26	4.38		15.16	3.29		11.40	5.01		17.33				
N (SP)		3.98		11.93	3.50		10.49	2.34		7.01	3.20		9.59				
Z (SSP)		3.04		NS	3.86		NS	3.40		NS	2.99		NS				
M x N		7.96		NS	7.00		NS	4.67		NS	6.40		NS				
M x Z		6.08		NS	7.72		NS	6.80		NS	5.98		NS				
N x Z		5.26		NS	6.68		NS	5.89		NS	5.18		NS				
M x N x Z		10.52		NS	13.37		NS	11.77		NS	10.35		NS				
Control vs Rest		15.14		26.20	16.09		27.84	12.10		20.94	18.40		31.83				

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M) 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 6: Soil available sulphur (kg ha⁻¹) at panicle initiation and harvest stages of paddyas influenced by different levels of nitrogen along with foliar spray of nano nitrogen and nano zinc during *rabi*(pooled 2021 and 2022)and*kharif*(2021)

MxNxZ		Panicle initiation								At harvest							
		<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021				<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021			
		N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ
M ₁	Z ₁	19.14	19.84	18.40	19.13	20.01	20.73	18.91	19.88	16.02	16.61	15.42	16.02	15.59	16.17	15.26	15.67
	Z ₂	18.77	19.31	18.12	18.73	19.54	20.14	18.63	19.44	15.71	16.17	15.18	15.69	15.35	15.77	15.01	15.38
M ₂	Z ₁	16.15	16.73	15.35	16.08	17.50	18.34	16.64	17.49	13.49	13.97	12.83	13.43	12.66	12.95	12.04	12.55
	Z ₂	15.71	16.25	15.01	15.66	16.91	17.38	16.31	16.87	13.13	13.59	12.54	13.09	12.41	12.93	11.74	12.36
M ₃	Z ₁	18.91	19.41	17.55	18.62	19.49	20.14	18.38	19.34	15.84	16.26	13.67	15.26	15.63	15.94	14.27	15.28
	Z ₂	17.81	18.90	17.21	17.98	18.88	20.03	18.23	19.05	14.90	15.82	13.41	14.71	14.31	15.19	13.83	14.44
M ₄	Z ₁	21.55	22.40	20.83	21.59	21.97	22.90	21.40	22.09	17.10	17.78	16.53	17.14	18.01	18.67	17.27	17.98
	Z ₂	21.35	21.87	20.30	21.17	21.81	22.22	20.89	21.64	16.94	17.35	16.11	16.80	17.80	18.32	16.81	17.64
N		18.67	19.34	17.85		19.51	20.24	18.67		15.39	15.94	14.46		15.22	15.74	14.53	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	18.95	19.57	18.26	18.93	19.78	20.44	18.77	19.66	15.87	16.39	15.30	15.85	15.47	15.97	15.13	15.53
	M ₂	15.93	16.49	15.18	15.87	17.21	17.86	16.48	17.18	13.31	13.78	12.69	13.26	12.54	12.94	11.89	12.46
	M ₃	18.36	19.16	17.38	18.30	19.18	20.08	18.30	19.19	15.37	16.04	13.54	14.98	14.97	15.56	14.05	14.86
	M ₄	21.45	22.13	20.57	21.38	21.89	22.56	21.15	21.87	17.02	17.57	16.32	16.97	17.90	18.49	17.04	17.81
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	18.94	19.59	18.03	18.85	19.74	20.53	18.83	19.70	15.62	16.15	14.61	15.46	15.47	15.93	14.71	15.37
	Z ₂	18.41	19.08	17.66	18.38	19.28	19.94	18.52	19.25	15.17	15.73	14.31	15.07	14.97	15.55	14.35	14.96
Control		10.59				10.61				8.50				9.02			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M (MP)		0.20		0.69		0.18		0.61		0.14		0.48		0.20		0.68	
N (SP)		0.19		0.57		0.21		0.63		0.16		0.48		0.18		0.44	
Z (SSP)		0.18		NS		0.20		NS		0.16		NS		0.15		NS	
M x N		0.38		NS		0.42		NS		0.32		NS		0.36		NS	
M x Z		0.37		NS		0.39		NS		0.31		NS		0.31		NS	
N x Z		0.32		NS		0.34		NS		0.27		NS		0.26		NS	
M x N x Z		0.64		NS		0.68		NS		0.54		NS		0.53		NS	
Control vs Rest		0.74		1.27		0.64		1.12		0.51		0.88		0.73		1.26	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)

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

MxNxZ		Panicle initiation								At harvest							
		<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021				<i>Rabi</i> (Pooled 2021 and 2022)				<i>Kharif</i> -2021			
		N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ	N ₁	N ₂	N ₃	MxZ
M ₁	Z ₁	1.19	1.25	1.20	1.21	1.25	1.31	1.26	1.27	1.10	1.16	1.11	1.12	1.16	1.22	1.17	1.18
	Z ₂	1.15	1.24	1.19	1.19	1.21	1.30	1.25	1.25	1.06	1.15	1.10	1.10	1.12	1.21	1.16	1.16
M ₂	Z ₁	1.05	1.08	1.03	1.05	1.11	1.14	1.09	1.11	0.95	0.98	0.93	0.95	1.01	1.04	0.99	1.01
	Z ₂	1.04	1.05	1.01	1.03	1.10	1.11	1.07	1.09	0.94	0.95	0.91	0.93	1.00	1.01	0.97	0.99
M ₃	Z ₁	1.10	1.17	1.06	1.11	1.16	1.23	1.12	1.17	1.01	1.08	0.97	1.02	1.07	1.14	1.03	1.08
	Z ₂	1.07	1.15	1.04	1.09	1.13	1.21	1.10	1.15	0.98	1.06	0.95	1.00	1.04	1.12	1.01	1.06
M ₄	Z ₁	1.14	1.20	1.14	1.16	1.20	1.26	1.19	1.22	1.05	1.13	1.04	1.07	1.11	1.17	1.10	1.13
	Z ₂	1.12	1.17	1.12	1.13	1.18	1.23	1.18	1.19	1.03	1.08	1.03	1.04	1.09	1.14	1.09	1.10
N		1.11	1.16	1.10		1.17	1.22	1.16		1.01	1.07	1.00		1.07	1.13	1.06	
		MxN			M	MxN			M	MxN			M	MxN			M
M	M ₁	1.17	1.24	1.20	1.20	1.23	1.30	1.26	1.26	1.08	1.15	1.11	1.11	1.14	1.21	1.17	1.17
	M ₂	1.04	1.06	1.02	1.04	1.10	1.12	1.08	1.10	0.94	0.96	0.92	0.94	1.00	1.02	0.98	1.00
	M ₃	1.08	1.16	1.05	1.10	1.14	1.22	1.11	1.16	0.99	1.07	0.96	1.01	1.05	1.13	1.02	1.07
	M ₄	1.13	1.19	1.12	1.14	1.19	1.25	1.18	1.20	1.04	1.10	1.03	1.05	1.10	1.16	1.09	1.11
		NxZ			Z	NxZ			Z	NxZ			Z	NxZ			Z
Z	Z ₁	1.12	1.17	1.10	1.13	1.18	1.23	1.16	1.19	1.03	1.08	1.01	1.04	1.09	1.14	1.07	1.10
	Z ₂	1.09	1.15	1.09	1.11	1.15	1.21	1.15	1.17	1.00	1.06	1.00	1.02	1.06	1.12	1.06	1.08
Control		0.62				0.63				0.52				0.51			
		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %		S.Em ±		CD at 5 %	
M (MP)		0.05		0.01		0.03		0.03		0.10		0.05		0.01		0.03	
N (SP)		0.04		0.02		0.04		0.01		0.03		0.03		0.01		0.03	
Z (SSP)		NS		0.01		NS		0.01		NS		NS		0.01		NS	
M x N		NS		0.04		NS		0.02		NS		NS		0.02		NS	
M x Z		NS		0.02		NS		0.02		NS		NS		0.02		NS	
N x Z		NS		0.02		NS		0.02		NS		NS		0.02		NS	
M x N x Z		NS		0.04		NS		0.04		NS		NS		0.04		NS	
Control vs Rest		0.08		0.04		0.07		0.10		0.18		0.09		0.03		0.06	

NOTE:

NS : Non significant

Main plot : Soil nitrogen management (M)

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