Original Research Article

ASSESSING THE DIFFERENTIAL EFFECTS OF CONVENTIONAL & NANO FERTILIZERS ON SOIL NUTRIENT STATUS, USE EFFICIENCY & BIOLOGICAL ACTIVITY IN ACIDIC SOIL

ABSTRACT:

A two-season field experiment was conducted at zonal agricultural research station, GKVK, Bengaluru during *Kharif* season in 2021 and 2022 with test a crop sunflower. The soil was sandy loam (Alfisol) in texture and experiment was laid out in RCBD with 3 replications and comprised of 14 treatments. Results revealed that the available soil nutrients like nitrogen (307.25 kg ha^{-1}), sulphur (13.28 mg kg^{-1}) and zinc (1.23 mg kg^{-1}) content differed significantly, with treatment T_2 (Package of practice). However, all other major, secondary and micro nutrients did not vary significantly. Nutrients use efficiency of nitrogen (72.01 kg kg^{-1}), phosphorus (26.47 kg kg^{-1}) and potassium (35.29 kg kg^{-1}) were recorded higher withnano fertilizers than conventional one. Urease activity (22.42 µg NH_4-N g^{-1} hr^{-1}) was found to be significantly higher in treatment T_2 (Package of practice) and enzyme activity like dehydrogenase activity and acid phosphatase activity not significantly varied, the numerical difference was regulated by pH of soil. Combination of conventional and nano fertilizers can be effectively utilized in enhancing the nutrients use efficiency while sustainably managing the soil properties.

KEYWORDS: Nano-Fertilizer, soil nutrients, sunflower, efficiency, acidic soil, biological activity

INTRODUCTION:

Modern agriculture faces an ever-growing challenge to simultaneously meet the escalating global demand for food while ensuring environmental sustainability (Shen *et al.,* 2015). Fertilizers play a pivotal role in augmenting crop productivity, and as such, the exploration of novel fertilization strategies is imperative. Within this context, nanotechnology has emerged as a groundbreaking avenue, promising to redefine the dynamics of nutrient delivery and efficiency of utilization in plants (Moshe *et al.*, 2012). This study undertakes a detailed examination to unravel the intricate effects of conventional and nano fertilizers on soil nutrient status, use efficiency, and biological activity, with a particular emphasis on the intricate milieu of acidic soil environments.

Acidic soils, characterized by a pH below 7, encompass vast expanses of arable land globally, presenting distinctive challenges to sustainable agriculture. The chemical and physical properties of acidic soils significantly impact nutrient availability and plant growth, necessitating a nuanced understanding of fertilizer interactions (Helaly *et al.,* 2014). This study aims to bridge this knowledge gap by scrutinizing the responses of acidic soils to conventional and nano fertilizers, shedding light on their distinct mechanisms and potential benefits in mitigating the challenges posed by soil acidity.

Conventional fertilizers, based on time-tested formulations, have been integral to agricultural practices for decades, offering a reliable means of replenishing essential nutrients. However, their efficacy in acidic soils may be compromised due to factors such as nutrient immobilization and reduced microbial activity (De Rosa *et al*., 2010). Nano fertilizers, on the other hand, present a novel approach, with their nano-sized particles potentially overcoming the limitations of conventional fertilizers. The increased surface area of nano-sized particles facilitates improved nutrient release and uptake, potentially enhancing nutrient use efficiency in acidic soils (Helaly *et al.,* 2014).

This study adopts a multifaceted approach, encompassing field trials to assess the impact of both fertilizer types on soil nutrient status. Beyond nutrient dynamics, the study delves into the realm of soil biology, exploring how conventional and nano fertilizers influence the composition and activity of microbial communities (Shen *et al.,* 2015). Microbes and enzymes are vital contributors to nutrient cycling, and their responses to different fertilizers can significantly impact overall soil health and fertility as related by Corradini *et al*. (2010). Enzymatic activities and other crucial indicators of soil biological activity will be analyzed to provide a comprehensive understanding of the broader ecosystem implications of fertilizer applications in acidic soils.

In sum, this research aspires to contribute essential insights into optimizing fertilizer use in acidic soils, paving the way for sustainable and tailored agricultural practices. By deciphering the intricate balance between conventional and nano fertilizers in acidic environments, this study aims to guide agricultural strategies towards increased efficiency, reduced environmental impact, and ultimately, enhanced food security in the face of evolving global challenges.

MATERIAL AND METHODS:

Preliminary Soil analysis: Prior to field experimentation the surface soil sample from the experimental site was collected, processed and analyzed for the parameters like Soil texture, bulk density, maximum water holding capacity, pH, electrical conductivity, organic carbon, N, P_2O_5, K_2O (major nutrient), Ca, Mg, S (secondary nutrient), Fe, Zn, Mn, Cu (micro nutrient) using standard protocols and the data obtained are presented in Table 1.

Experimental details: A two season field experiment was conducted at zonal agricultural research station, GKVK, Bengaluru during *Kharif* season in 2021 and 2022 with sunflower as test crop. The high yielding variety KBSH-44 was used for the experiment at seed rate of 5 kg/ha and recommended dose of FYM (6.25t/ha) and fertilizer (37.5:50:37.5 kg/ha of NPK + 10 kg/ha $ZnSO_4$ + 15 kg/ha Borax + 375 g/ha Azatobactor) was applied according to the treatment. The soil type was sandy loam (Alfisol) in texture and the experiment was laid out in randomized block design with 3 replications and comprised of 14 treatments.

List 1. Treatment details:

T_1: Absolute control
T_2: Package of practice (FYM + Bio fertilizers + NPK + Zn + B)
T_3:25% RDN + nU @ 0.2% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_4:25% RDN + nU @ 0.4% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_5:50% RDN + nU @ 0.2% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_6:50% RDN + nU @ 0.4% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_7:75% RDN + nU @ 0.2% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_8:75% RDN + nU @ 0.4% + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm
T_9:25% RDN + nU @ 0.2% + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm
T_{10}:25% RDN + nU @ 0.4% + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm
T_{11}:50% RDN + nU @ 0.2% + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm
T_{12}:50% RDN + nU @ 0.4% + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm
T_{13}:75% RDN + nU @ 0.2% + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm
T_{14}:75% RDN + nU @ 0.4% + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm

Note: nU – Nano Urea, nS – Nano Sulphur, nZn – Nano Zinc

FYM, Bio fertilizer, Phosphorus, Potassium and Borax is common for all treatments except in absolute control.

Spray Schedule of Nano fertilizers: Nano Urea spray – Vegetative V4 and Pre Bud-initiation stage @ 20 and 40 DAS +Nano Sulphur and Zinc spray - Ray floret stage @ 50-55 DAS

After harvest soil analysis: Nutrients status of N, P_2O_5, K_2O (major nutrient), Ca, Mg, S (secondary nutrient), Fe, Zn, Mn, Cu (micro nutrient) were analyzed using the following protocols. The available nitrogen in soil was determined by alkaline potassium permanganate method as described by Subbaih and Asija (1956). The available phosphorus from the soil sample was extracted using Bray's No.1 extractant and measured using a chloro-stannous reduced phospho-molybdenum blue color process (Bray and Kurtz, 1945). Available potassium was extracted with neutral normal ammonium acetate solution and was determined using flame-photometry as described by Page *et al.* (1982).

The amount of Calcium and Magnesium in the soil sample was measured using Jackson (1973) versenate titration technique.Available sulphur in the soil was extracted from soil by using 0.15 per cent calcium chloride and estimated by Turbidometric method using $BaCl_2$ as stabilizing agent by Black (1965).The micronutrients such as Fe, Zn, Mn & Cu was measured using the process of extraction from DTPA and estimation by AAS as established by Lindsay and Norwell (1978).

Nutrients use efficiency (NUE):it's a critically important concept in the evaluation of crop production systems and fertilizer evaluation system. Nutrient use efficiency of Nitrogen, Phosphorus and potassium was calculated using the formula:

$$\text{NUE (kg kg}^{-1}\text{)} = \frac{\text{Grainyieldoffertilized plot(kg)} - \text{Grainyieldofcontrolplot (kg)}}{\text{Quantityofnutrientapplied(kg)}}$$

Soil biological activity: The dehydrogenase activity in the soil samples was determined by mixing with $CaCO_3$ and TTCincubated at 37 ^{o}Cfor 24 hours, later, methanol was added and intensity of red colour was estimated in spectrophotometer as described by Casida *et al.* (1964) and the dehydrogenase activities of the samples were expressed as µg TPF formed per gram of sample per 24 hours. The urease activity of the soil samples was determined by treating with urea solution incubated at 37^{o}C, later, shaken with KCl – PMA and red colour developed the further process was measured in spectrophotometer as the method given by Eivazi and Tabatabai (1977) and Expressed the urease activity as µg NH_4-N g^{-1} hr^{-1}. Acid Phosphatase activities were estimated by treating soil with toluene, universal buffer and PNP, later, extracted with $CaCl_2$ and NaOH and yellow colour intensity was estimated in spectrophotometer as per the procedure described by Eivazi and Tabatabai (1977) and expressed as micrograms of PNP per gram per hour.

Statistical analysis of Data: The experimental data collected on various soil properties, growth and yield parameters of sunflower plant was subjected to Fishers method of Analysis of Variance (ANOVA) as outlined by Gomez and Gomez (1984). Where ever the F- test will found significant for comparison among treatment means, an appropriate value of critical difference (CD) has been worked out. Otherwise the abbreviation NS is indicated against the CD values. All the data were analyzed and the results are presented and discussed at a probability level of 5 per cent for field experiment and 1 per cent for laboratory experiment.

RESULTS AND DISCUSSION

Soil nutrients status:

Available soil nutrients like Nitrogen, Sulphur and Zinc content differed significantly due to application of different levels of urea and zinc sulphate fertilizer to soil and foliar spray of nano fertilizers (Table. 2, 3 and 4). The available nitrogen (307.25 kg ha^{-1}), available Sulphur (13.28 mg kg^{-1}) and zinc (1.23 mg kg^{-1}) recorded the highest in treatment T_2, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and it was on par with treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm). Significantly low nitrogen, sulphur and zinc were observed in absolute control. In contrast, all other major, secondary and micro nutrients after the harvest of sunflower did not vary among treatments significantly with application of different levels of nitrogen and zinc sulphate fertilizer to soil.

The application of nitrogen fertilizer and zinc sulphate to soil can increase the soil's nitrogen pool. Nitrogen fertilizer stimulates soil microorganism activity, leading to increased mineralization of organic matter, releasing nutrients into the soil as mentioned by Kottegoda*et al*. (2011). Zinc sulphate reduces nitrogen losses from the soil, as it is essential for plant growth and development. Plants need enough zinc to absorb more nitrogen from the soil, reducing nitrogen losses and enhance the availability (Helaly *et al.,* 2014). Nutrients fertilizers can be inorganic or organic, with inorganic being readily available to plants. Zinc sulphate is essential for plant growth and development, involved in processes like photosynthesis, nitrogen metabolism, and auxin synthesis. Plants lacking zinc struggle to absorb nutrients efficiently from the soil (De Rosa *et al*., 2010). More over application of nutrients through foliar mode reduce the pressure and demand of nutrients from soil (Shen *et al.,* 2015). Combining nitrogen fertilizer and zinc sulphate can increase the soil's nitrogen, sulphur and zinc pool in various ways as related by Corradini *et al*. (2010).

Nutrients use efficiency (NUE):

Data on Nutrients use efficiency (kg kg^{-1}) by sunflower showed variation due to different levels of nano nitrogen, sulphur and zinc practice and are presented in Table 5. Results showed that with the application of 25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm (T_{10}) recorded higher Nitrogen (N) use efficiency (kg kg^{-1}) by sunflower *i.e*., 72.01 kg kg^{-1} that was on par with treatment T_9 (25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm) which recorded 65.82 kg kg^{-1}. In case of Phosphorus (P) and Potassium (K) use efficiency, treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm) recorded higher nutrient use efficiency (26.47 and 35.29 kg kg^{-1} Phosphorus and Potassium use efficiency, respectively) over treatment T_2 (15.54 and 20.72 kg kg^{-1} Phosphorus and Potassium use efficiency, respectively) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B)

The application of nitrogen, zinc sulphate and nano nutrients as foliar sprays to sunflower plants can enhance nutrient use efficiency. Adjusting nitrogen levels in the soil can improve nutrient availability for sunflower plants, promoting better absorption and utilization of phosphorus and potassium as indicated by WA Al-juthery *et al.* (2019). Zinc sulphate application optimizes zinc availability, which is crucial for physiological processes like nutrient uptake and enzyme activation. Properly calibrated levels of nitrogen, phosphorus, and potassium ensure a balanced nutrient ratio in the soil, promoting optimal plant growth and development as recorded by Badran and Savin (2017). Nano nutrients as foliar sprays provide a precise and easily absorbable form of nutrients, helping maintain an appropriate balance. Nano-sized particles in foliar sprays can penetrate plant tissues more effectively, leading to increased nutrient uptake efficiency as stated by Sumathi and Koteswara Rao (2007). Nitrogen application positively influences soil structure, promoting aeration and water infiltration, and enhancing microbial activity. Zinc sulphate contributes to improved microbial activity, supporting nutrient mineralization and release. Adequate nitrogen levels stimulate enzymatic activity in plants, which is essential for nutrient metabolism. Zinc sulphate application addresses zinc deficiencies, which can be a limiting factor for nutrient uptake in plants as mentioned by Jhanzab*et al*. (2015). Nano-sized nutrients in foliar sprays offer a quick and targeted solution to nutrient deficiencies, ensuring the plant has access to essential elements when needed. Nano-sized nutrients may have reduced environmental impact compared to conventional forms, as they can be more targeted in their action, minimizing runoff and leaching as outlined byBurmana*et al*. (2013).

Soil biological activity:

Dehydrogenase activity (DHA) is an index of microbial activity in the soil. A perusal of the data on soil dehydrogenase activity (Table 6) revealed that it varied from 71.63 to 75.53 µg TPF g^{-1} $24hr^{-1}$ and the numerically highest in treatment T_9 (25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm) (75.53 µg TPF g^{-1} $24hr^{-1}$) when compared with treatments. Results on acid phosphatase activity (Table 6) revealed that among different treatments it did not influence significantly ($p<0.05$). However, numerically higher acid phosphatase activity (33.70 µg PNP g^{-1} hr^{-1}) was observed in T_2*i.e.,* Package of practice (FYM + Bio fertilizers + NPK + Zn + B). This would imply that the activity of acid phosphatase had a direct relationship with the pH of the soil. Moreover, application of Different levels nano nitrogen, sulphur and zinc also augmented the acid phosphate activity. lower acid phosphatase activity was recorded in absolute control (31.93 µg PNP g^{-1} hr^{-1}). Different levels of nano nitrogen, sulphur and zinc practice had an influence significantly ($p<0.05$) on Urease activity after harvest of sunflower crop and the data is presented in Table 5. Among all the treatments, soil applied with treatments T_2(22.42 µg NH_4-N g^{-1} hr^{-1}) *i.e.,* Package of practice (FYM + Bio fertilizers + NPK + Zn + B) showed superior results over treatment T_1 (absolute control) which was closely followed with soil applied treatment T_{14} *i.e.,*75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm treatment recorded 22.07 µg NH_4-N g^{-1} hr^{-1} that is on par with $T_{13,}$ $T_{8,}$ $T_{7,}$ T_6 (21.47, 21.47, 21.22, 21.10 µg NH_4-N g^{-1} hr^{-1}, respectively) and minimum nitrogen content in seed (15.01 µg NH_4-N g^{-1} hr^{-1}) was recorded in absolute control (T_1)

Nitrogen fertilizer *i.e*urea is essential nutrients for soil microorganisms, supporting their growth and metabolic activities. Nitrogen, in the form of ammonium or nitrate, serves as a direct energy source for soil urease enzyme, leading to increased growth rates and higher activity by providing higher substrate as food and energy source as noted by Zhou *et al.* (2015). Adequate nitrogen and zinc levels stimulate soil microorganisms to produce more enzymes, which facilitate efficient nutrient turnover in the soil. Nitrogen is also crucial for the decomposition of organic matter, acting as an energy source for decomposers. Zinc sulphate can impact soil pH, ensuring it remains suitable for microbial growth and enzyme activity. Maintaining an optimal pH range is important for soil microbial activity, and adequate zinc levels help regulate soil pH as stated by Shen *et al.*(2015). Nitrogen and zinc are vital for achieving balanced nutrient ratios in the soil, preventing nutrient imbalances that might limit enzymatic activity. The application of nitrogen and zinc sulphate can help maintain soil health by supporting beneficial microbial populations, which are essential for organic matter decomposition, nutrient mineralization, and overall soil ecosystem stability. Adequate nutrients help soil microbes better withstand environmental stressors, such as nutrient deficiencies or imbalances, which can hinder their activities (Moshe *et al.*, 2012). Enhanced microbial activity, enzyme production, and nutrient cycling create a positive feedback loop that benefits the entire soil ecosystem. Proper application of nutrients, such as nitrogen and zinc sulphate, can minimize nutrient leaching and runoff, ensuring that essential elements remain available for microbial use in the soil. This was in line with Corradini *et al*. (2010) and Collins *et al.* (2012).

CONCLUSION:

With the application of different levels of conventional & nano fertilizers it had a significant effect on soil nutrient status, use efficiency & biological activity in acidic soil. Nano-fertilizers can be effectively used in acidic soil and its effect on various soil properties are very minimal and can improve the biological activity in acidic soil. They offer precise application, reduced labour and improved nutrients use efficiency. This approach is cost-effective and enhances soil health. It aligns with sustainable farming methods.

REFERENCES:

BADRAN, A. AND SAVIN, I., 2017, Effect of nano-fertilizer on seed germination and first growth stages of bitter almond (*Prunus dulcis* var. *amara*). *J. Plant Nutr.,* **40**(10): 1439-1447.

BLACK, C. A., 1965 Methods of soil analysis part-1 physical and mineralogical properties. Agronomy Monograph No.9. *American Soc. Agron.* Madison, Wisconsin, USA, **7**: 18-25.

BRAY, R. H. AND KURTZ, L. T., 1945, Determination of total, organic, and available forms of phosphorus in soils. *Soil Sci.,* **59**(1): 39-46.

BURMANA, U., SAINIB, M. AND PRAVEENKUMAR, S., 2013, Effect of zinc oxide nanoparticles on growth and antioxidant system of chickpea seedlings. *Toxicol. Environ. Chem*., **95** (4): 605 - 612.

CASIDA, L. E., KLEIN, D. A. AND SANTOTO, T., 1964, Soil dehydrogenase activity.*Soil Sci.*,**98**: 371-376.

COLLINS, D., LUXTON, T., KUMAR, N., SHAH, S. AND WALKER, V. K., 2012, Assessing the impact of copper and zinc oxide nanoparticles on soil: a field study. *PLoS One*, **7** (8): 42663.

CORRADINI, E., TEIXEIRA, E. D., DE MOURA, M. R., MUZZARELLI, R. A. A., AND MATTOSO, L. H. C., 2010, Preparation of chitosan nanoparticles for loading with NPK fertilizer. *Afr. J. Biotechnol.*, **9**(18): 2691-2696.

DE ROSA, M. C., MONREAL, C., SCHNITZER, M., WALSH, R. P., AND SULTAN, Y., 2010, Nanotechnology in fertilizers. *Nat. Nanotechnol.*, **5**(2): 91-99.

EIVAZI, F. AND TABATABAI, M. A., 1977, Phosphatases in soils. *Soil Biol. Biochem*.,**9**:167-177.

GOMEZ, K.A. AND GOMEZ, A.A., 1984, Statistical procedures for agricultural research. John wiley& sons.

HELALY, M. N., EL-METWALLY, M. E., EL-HOSEINY, H., OMAR, S. A. AND ELSHEERY, N. I., 2014, Effect of nanoparticles on biological contamination of in vitro cultures and organogenic regeneration of banana. *Aust. J. Crop Sci.,* **8**(4): 612-624.

JACKSON, M.L., 1973, *Soil chemical analysis*. Prentice Hall of India, New Delhi, **1**: 485-486

JHANZAB, H. M., FAROOQ, M., WAHID, A., HUSSAIN, M. AND SIDDIQUE, K. H. M., 2015, Sulphur nano particles improve nitrogen use efficiency in wheat. Journal of Plant Nutrition, **38**(12): 1821-1831.

KOTTEGODA, N., MUNAWEERA, I., MADUSANKA, N. AND KARUNARATNE, V., 2011, A green slow-release fertilizer composition based on urea-modified hydroxyapatite nanoparticles encapsulated wood. *Curr. Sci.,***64**(2): 73-78.

LINDSAY, W.L. AND NORWELL, W.A., 1978, Development of DTPA soil test for zinc, iron, manganese and copper. *Soil Sci. Soc. Amer. J*., **42**: 421-428.

MOSHE, Y., OKUN, E. AND HENNY, C., 2012, Effect of metal oxide nanoparticles (ZnO and Fe3O4) on soil properties, bacterial community composition and enzymatic activity. *Appl. Environ. Microbiol.,***78**(2): 408-417.

PAGE, A. L, MILLER, R. H. AND KENAY, D. R., 1982, *Methods of Soil Analysis, part – 2, Soil Science Society of America*, Inc, Publishers, Madison, Wisconsin, USA.

SHEN, Y., HE, Z. L., LU, H. Y., YANG, K. AND HUANG, Q., 2015, Eco-toxicological effects of zinc oxide nanoparticles on soil microorganisms. *Environ. Toxicol. Chem,***34**(11): 2522-2530.

SUBBAIH, A. Y. AND ASIJA, G. K., 1956, A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.,* 25: 270-280.

SUMATHI, P. AND KOTESWARA RAO, N., 2007, Effect of Integrated Nitrogen Management on Growth, Yield and Nutrient Uptake of Sunflower. *Indian J. Plant Physiol.,***12**(1): 46-51.

WA AL-JUTHERY, H. AND HILAL OBAID AL-MAAMOURI, E., 2020, Effect of Urea and NanoNitrogen Fertigation and Foliar Application of Nano-Boron and Molybdenum on some Growth and Yield Parameters of Potato. *Al-Qadisiyah*.***J. Agric. Sci*.**, **10**(1): 253 - 263.

ZHOU, J., QIN, S., LIU, X. AND ZHANG, C., 2015, Effects of Different Nitrogen Fertilizer Application Rates on Soil Physical Properties and Rice Yield. *Pedosphere*, **25**(6): 733-741.

Table1: Standard Methods employed and Initial physico-chemical properties of the soil of experimental area

Season	2021	2022
Parameters	**Value**	
pH	5.81	5.84
EC (dS m^{-1})	0.11	0.12
MWHC (%)	1.39	1.38
Bulk density (g/cc)	30.59	30.92
Organic carbon (%)	0.49	0.50
Available Nitrogen (kg ha^{-1})	280.59	306.96
Available Phosphorus (kg ha^{-1})	22.29	26.71
Available Potassium (kg ha^{-1})	154.90	159.69
Exchangeable Calcium (c mol (p+) kg^{-1})	2.80	3.47
Exchangeable Magnesium (c mol (p+) kg^{-1})	1.55	1.92
Available Sulphur (mg kg^{-1})	10.16	11.56
DTPA extractable Iron (mg kg^{-1})	7.55	8.10
Zinc (mg kg^{-1})	0.72	0.90
DTPA extractable Manganese (mg kg^{-1})	4.30	4.56
DTPA extractable Copper (mg kg^{-1})	0.24	0.26

Table 2. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on available major nutrient (Nitrogen, Phosphorus and Potassium)(kg ha^{-1}) status of soilafter the harvest of sunflower

Treatments	Details	Available Nitrogen (kg ha^{-1})			Available Phosphorus (kg ha^{-1})			Available Potassium (kg ha^{-1})		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1	Absolute control	270.96	295.39	283.17	20.88	23.90	22.39	150.50	155.11	152.80
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	291.92	322.59	307.25	24.51	31.86	28.19	158.56	165.30	161.93
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	275.56	302.44	289.00	25.31	32.90	29.11	161.59	168.46	165.02
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	275.91	301.82	288.87	25.18	32.73	28.96	159.84	166.63	163.23
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	279.21	307.44	293.33	24.86	32.32	28.59	159.32	166.09	162.70
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	280.09	307.41	293.75	24.59	31.97	28.28	158.28	165.00	161.64
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	284.12	311.93	298.03	24.49	31.84	28.16	157.82	164.53	161.17
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	285.41	314.25	299.83	24.35	31.66	28.00	157.61	164.31	160.96
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	277.62	304.7	291.16	25.24	32.81	29.03	160.88	167.71	164.29
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	277.01	304.97	290.99	25.09	32.62	28.85	160.36	167.17	163.76
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	280.38	309.73	295.05	24.75	32.18	28.46	159.19	165.95	162.57
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	281.93	309.43	295.68	24.67	32.07	28.37	158.73	165.48	162.10
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	288.01	317.1	302.56	24.42	31.75	28.08	157.75	164.45	161.10
T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	288.54	318.68	303.61	24.28	31.56	27.92	157.39	164.08	160.73
	S.Em ±	**7.96**	**8.75**	**8.53**	**0.70**	**0.91**	**0.80**	**4.52**	**4.71**	**4.16**

	CD @ 5%	23.15	25.42	24.29	NS	NS	NS	NS	NS	NS

Table 3. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on secondary nutrients (Exchangeable Calcium, Magnesium (cmol (p^+) kg^{-1}) and Available Sulphur (mg kg^{-1})) status of soilafter the harvest of sunflower

Treatments	Details	Ex. Calcium (c mol (p^+) kg^{-1})			Ex. Magnesium (c mol (p^+) kg^{-1})			Available Sulphur (mg kg^{-1})		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T_1	Absolute control	2.74	3.40	3.07	1.53	1.90	1.72	5.99	7.37	6.68
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	2.82	3.50	3.16	1.58	1.96	1.77	12.91	13.65	13.28
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.91	3.62	3.26	1.63	2.03	1.83	11.09	13.27	12.18
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.90	3.60	3.25	1.62	2.02	1.82	10.96	13.12	12.04
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.86	3.55	3.21	1.60	1.99	1.80	10.71	12.82	11.76
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.83	3.52	3.17	1.58	1.97	1.78	10.56	12.64	11.60
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.82	3.50	3.16	1.58	1.96	1.77	10.41	12.46	11.43
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	2.80	3.48	3.14	1.57	1.95	1.76	10.35	12.39	11.37
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	2.90	3.61	3.25	1.63	2.02	1.82	8.29	9.92	9.11
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	2.89	3.59	3.24	1.62	2.01	1.81	8.15	9.75	8.95
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	2.85	3.54	3.19	1.59	1.98	1.79	8.02	9.60	8.81
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	2.84	3.53	3.18	1.59	1.98	1.78	7.87	9.42	8.64
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	2.81	3.49	3.15	1.57	1.96	1.76	7.55	9.04	8.29
T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	2.79	3.47	3.13	1.56	1.94	1.75	7.32	8.76	8.04

	S.Em ±	**0.08**	**0.1**	**0.09**	**0.05**	**0.06**	**0.05**	**0.25**	**0.30**	**0.28**
	CD @ 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**0.74**	**0.87**	**0.81**

Table 4. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on DTPA extractable micronutrient (Iron, Zinc and Manganese)(mg kg^{-1}) status of soilafter the harvest of sunflower

Treatments	**Details**	**Iron (mg kg^{-1})**			**Zinc (mg kg^{-1})**			**Manganese (mg kg^{-1})**			**Copper (mg kg^{-1})**		
		2021	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**
T_1	Absolute control	7.44	7.97	7.70	0.58	0.73	0.65	4.22	4.48	4.35	0.22	0.25	0.24
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	7.68	8.22	7.95	1.09	1.37	1.23	4.34	4.61	4.48	0.23	0.26	0.25
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.93	8.48	8.20	0.89	1.12	1.00	4.46	4.74	4.60	0.25	0.27	0.26
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.79	8.33	8.06	0.88	1.10	0.99	4.39	4.67	4.53	0.24	0.27	0.25
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.75	8.29	8.02	0.87	1.09	0.98	4.37	4.64	4.51	0.24	0.26	0.25
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.66	8.20	7.93	0.85	1.07	0.96	4.33	4.60	4.47	0.23	0.26	0.25
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.63	8.16	7.89	0.82	1.03	0.92	4.31	4.58	4.45	0.23	0.26	0.24
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	7.61	8.14	7.88	0.81	1.02	0.91	4.30	4.57	4.44	0.23	0.26	0.24
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	7.87	8.42	8.14	0.69	0.86	0.78	4.44	4.71	4.57	0.24	0.27	0.26
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	7.83	8.37	8.10	0.67	0.84	0.75	4.41	4.69	4.55	0.24	0.27	0.26
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	7.73	8.28	8.01	0.65	0.81	0.73	4.37	4.64	4.50	0.24	0.26	0.25
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	7.70	8.24	7.97	0.62	0.78	0.70	4.35	4.62	4.48	0.23	0.26	0.25
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	7.62	8.16	7.89	0.61	0.76	0.69	4.31	4.58	4.44	0.23	0.26	0.24

T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	7.59	8.13	7.86	0.60	0.75	0.68	4.30	4.56	4.43	0.23	0.26	0.24
	S.Em ±	**0.22**	**0.23**	**0.23**	**0.02**	**0.03**	**0.02**	**0.12**	**0.12**	**0.12**	**0.01**	**0.01**	**0.01**
	CD @ 5%	**NS**	**NS**	**NS**	**0.06**	**0.08**	**0.07**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 5: Nutrients use efficiency (kg kg^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Nutrients use efficiency (kg kg^{-1}) by sunflower										
Treatments	**Details**	**Nitrogen**			**Phosphorus**			**Potassium**		
		2021	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**
T_1	Absolute control	-	-	-	-	-	-	-	-	-
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	21.30	20.14	20.72	15.97	15.10	15.54	21.30	20.14	20.72
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	53.17	52.28	52.72	9.97	9.80	9.89	13.29	13.07	13.18
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	62.59	57.08	59.84	11.74	10.70	11.22	15.65	14.27	14.96
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	52.78	51.37	52.08	19.79	19.27	19.53	26.39	25.69	26.04
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	57.93	55.80	56.86	21.72	20.92	21.32	28.97	27.90	28.43
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	39.18	38.45	38.82	22.04	21.63	21.83	29.39	28.84	29.11
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	45.59	42.85	44.22	25.65	24.10	24.87	34.19	32.14	33.16
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	66.51	65.13	65.82	12.47	12.21	12.34	16.63	16.28	16.45
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	73.36	70.66	72.01	13.76	13.25	13.50	18.34	17.66	18.00
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	55.90	52.24	54.07	20.96	19.59	20.28	27.95	26.12	27.03
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	60.93	57.62	59.28	22.85	21.61	22.23	30.47	28.81	29.64
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	42.79	41.22	42.00	24.07	23.18	23.63	32.09	30.91	31.50
T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	48.48	45.63	47.06	27.27	25.67	26.47	36.36	34.22	35.29
	S.Em ±									

	CD @ 5%									

Table 6. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on DehydrogenaseAcid phosphatase and Urease(µg g^{-1} hr^{-1}) status of soilafter the harvest of sunflower

Treatments	**Details**	**Dehydrogenase (µg TPF g^{-1} $24hr^{-1}$)**			**Acid phosphatase (µg PNP g^{-1} hr^{-1})**			**Urease (µg NH_4-N g^{-1} hr^{-1})**		
		2021	**2022**	**Pooled**	**2021**	**2022**	**Pooled**	**2021**	**2022**	**Pooled**
T_1	Absolute control	72.80	73.71	73.32	31.90	31.96	31.93	15.39	14.63	15.01
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	71.50	71.63	71.63	33.64	33.70	33.67	23.00	21.84	22.42
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	73.71	74.23	73.97	33.00	33.35	33.18	17.73	16.85	17.29
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	73.84	74.36	74.10	32.94	33.18	33.06	17.76	16.88	17.32
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	73.45	74.10	73.84	33.06	33.41	33.23	21.65	20.55	21.10
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	73.32	73.97	73.71	33.18	33.41	33.29	19.80	18.81	19.31
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	73.19	73.84	73.58	33.47	33.52	33.50	21.77	20.67	21.22
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	72.93	73.71	73.32	33.47	33.64	33.55	21.96	20.87	21.41
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	75.40	75.53	75.53	32.48	32.89	32.68	18.35	17.43	17.89
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	75.01	75.14	75.14	32.54	32.89	32.71	17.82	16.94	17.38
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	75.01	75.40	75.27	32.65	32.94	32.80	20.88	19.85	20.36
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	74.36	74.88	74.62	32.71	33.00	32.86	21.06	20.01	20.54
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	73.97	74.75	74.36	32.89	33.12	33.00	22.02	20.93	21.47
T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	74.10	74.88	74.49	32.77	33.06	32.92	22.64	21.51	22.07
	S.Em ±	**2.10**	**2.12**	**2.11**	**0.93**	**0.94**	**0.94**	**0.56**	**0.53**	**0.54**
	CD @ 5%	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**1.62**	**1.54**	**1.58**