

**EFFECT OF DIFFERENT LEVELS OF NANO
NITROGEN, SULPHUR AND ZINC ON SOIL
PROPERTIES, NUTRIENTS DYNAMICS AND
PRODUCTIVITY OF SUNFLOWER
IN ACIDIC SOIL**



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SCIENCES
BANGALORE**

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By
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**UNIVERSITY OF AGRICULTURAL
SCIENCES
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DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL
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BANGALORE

CERTIFICATE

This is to certify that the thesis entitled “Effect of different levels of nano nitrogen, sulphur and zinc on soil properties, nutrients dynamics and productivity of sunflower in acidic soil” submitted in partial fulfilment of the requirements for the award of **DOCTOR OF PHILOSOPHY** in **SOIL SCIENCE AND AGRICULTURAL CHEMISTRY** to the University of Agricultural Sciences, Bangalore is a record of *bona fide* research work carried out by **ROHITHA, D. S., PAMB 0105**, during the period of his study in this University under my guidance and supervision and no part of the thesis has been submitted for the award of any degree, diploma, associateship, fellowship or other similar titles.

Place: Bengaluru

May, 2024

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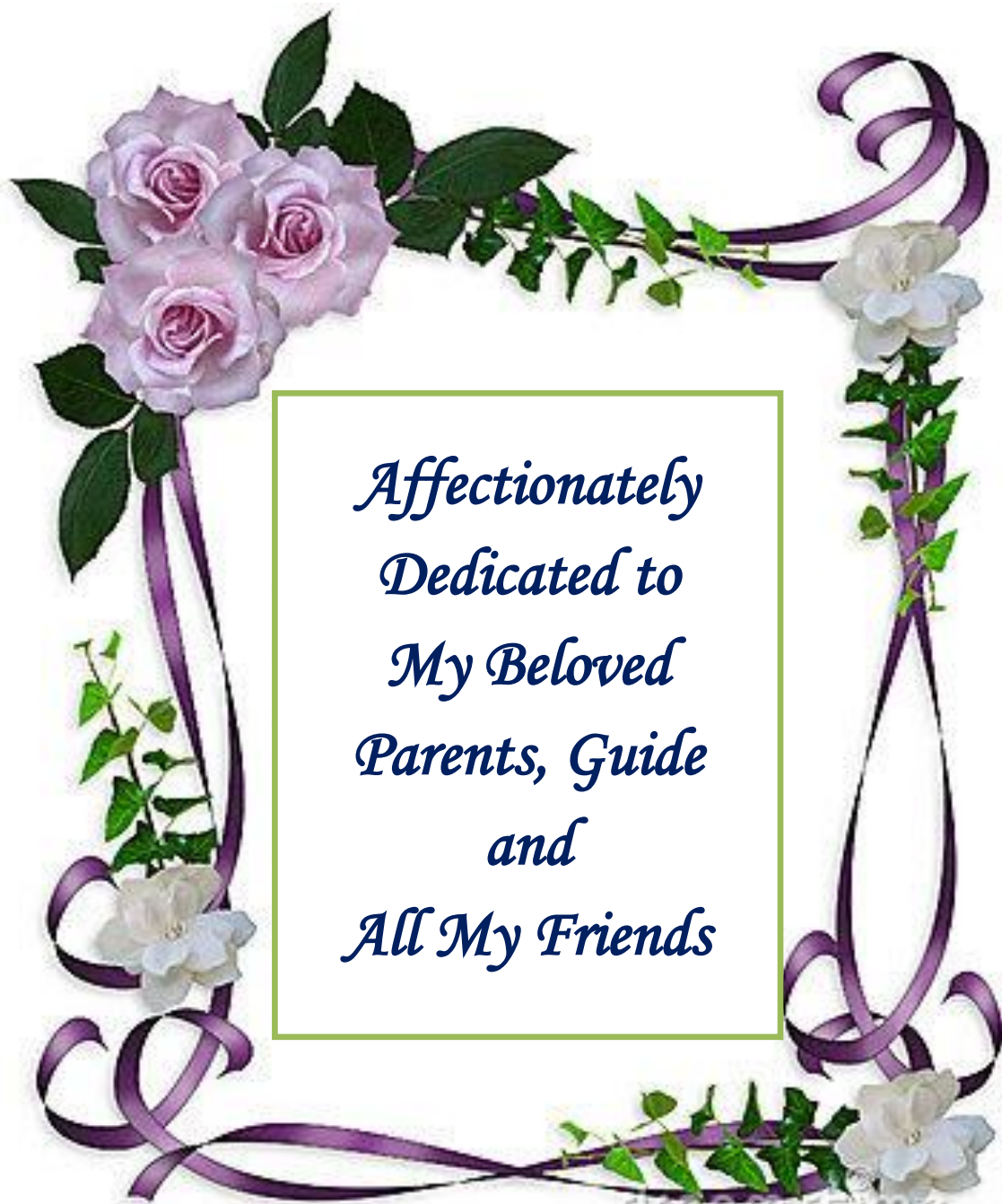
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*Affectionately
Dedicated to
My Beloved
Parents, Guide
and
All My Friends*

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With regardful memories.....

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ROHITHA, D. S.

ABSTRACT

A field experiment was conducted to study the effect of different levels of nano nitrogen, sulphur and zinc on soil properties, nutrients dynamics and productivity of sunflower in acidic soil at Zonal Agricultural Research Station, UASB, GKVK, Bengaluru-65 during *Kharif* 2021 and 2022. The experiment consisted of fourteen treatment combinations and replicated thrice in a Randomised Complete Block Design (RCBD) experimental layout. The results revealed that, soil physical properties were unaffected with different treatment combination. In the package of practice treatment, soil chemical properties like pH (5.51) and Electrical Conductivity (0.17 dS m^{-1}) and organic carbon didn't had a significant difference. However, biological property like urease activity ($22.42 \mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$), available soil nutrients like nitrogen ($307.25 \text{ kg ha}^{-1}$), sulphur and zinc (13.28 and 1.23 mg kg^{-1}) recorded to be significant and similarly, easily available nutrients fractions found to have a significant difference between treatments and at different intervals as well. Treatment with 75% RDN + nano urea at 4 ml/l + 25% zinc sulphate + nano sulphur at 200 ppm + nano zinc at 500 ppm is found to be significant over other treatments for improving growth, yield and quality parameters like plant height (212.69 cm), number of green leaves (30.24), number of filled seeds (943), seed and biomass yield (25.10 and 45.37 q ha^{-1}), protein and oil content (23.06 and 42.61 %). However, benefit cost ratio (3.03) recorded to be higher in treatment with 75% RDN + nano urea at 4 ml/l + 50% zinc sulphate + nano sulphur at 100 ppm + nano zinc at 250 ppm compared to all other treatment's combination.

May, 2024

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ಆವ್ಲ ಮಣ್ಣಿನ ಗುಣಲಕ್ಷಣ, ಪೋಷಕಾಂಶಗಳ ರೂಪಾಂತರವಿಕೆಯ ಮತ್ತು ಸೂರ್ಯಕಾಂತಿ ಸಸ್ಯಗಳ ಉತ್ಪಾದಕತೆಯ ಮೇಲೆ ವಿಭಿನ್ನ ಮಟ್ಟದಲ್ಲಿ ನೀಡಿದ ನ್ಯಾನೋ ರೂಪದ ಸಾರಜನಕ, ಗಂಧಕ ಮತ್ತು ಸತುವಿನ ಪರಿಣಾಮಗಳ ಅಧ್ಯಯನ

ರೋಹಿತ, ಡಿ. ಎಸ್.

ಸಾರಾಂಶ

ಬೆಂಗಳೂರು ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯದ ವಲಯ ಕೃಷಿ ಸಂಶೋಧನಾ ಕೇಂದ್ರ, ಗಾಂಧಿ ಕೃಷಿ ವಿಜ್ಞಾನ ಕೇಂದ್ರದ ಆವರಣದಲ್ಲಿ ೨೦೨೧ ಮತ್ತು ೨೦೨೨ರ ಮುಂಗಾರು ಹಂಗಾಮಿನಲ್ಲಿ ಆವ್ಲ ಮಣ್ಣಿನ ಗುಣಲಕ್ಷಣ, ಪೋಷಕಾಂಶಗಳ ರೂಪಾಂತರವಿಕೆಯ ಮತ್ತು ಸೂರ್ಯಕಾಂತಿ ಸಸ್ಯಗಳ ಉತ್ಪಾದಕತೆಯ ಮೇಲೆ ವಿಭಿನ್ನ ಮಟ್ಟದಲ್ಲಿ ನೀಡಿದ ನ್ಯಾನೋ ರೂಪದ ಸಾರಜನಕ, ಗಂಧಕ ಮತ್ತು ಸತುವಿನ ಪರಿಣಾಮಗಳ ಸಂಶೋಧನಾ ಪ್ರಯೋಗವನ್ನು ಕೈಗೊಳ್ಳಲಾಯಿತು. ಈ ಪ್ರಯೋಗದಲ್ಲಿರುವ ಹದಿನಾಲ್ಕು ಉಪಚಾರಗಳನ್ನು ಯಾದೃಚ್ಛಿಕ (ಆರ್.ಸಿ.ಬಿ.ಡಿ) ವಿನ್ಯಾಸದಲ್ಲಿ ೩ ಬಾರಿ ಪುನರಾವರ್ತನೆಗೊಳಿಸಲಾಗಿತ್ತು. ವಿವಿಧ ಉಪಚಾರಗಳೊಂದಿಗೆ, ಮಣ್ಣಿನ ಭೌತಿಕ ಗುಣಲಕ್ಷಣಗಳು ಬಾಧಿತವಾಗಿಲ್ಲ ಮತ್ತು ಶಿಫಾರಸ್ಸಿನ ಬೆಳೆ ಕೃಷಿಡಿಯ ಉಪಚಾರದಲ್ಲಿ, ಮಣ್ಣಿನ ರಾಸಾಯನಿಕ ಗುಣಲಕ್ಷಣಗಳಾದ ರಸಸಾರ (5.51), ವಿದ್ಯುತ್ವಾಹಕತ್ವ (0.17 ಡೆಸಿ ಸೀಮೆನ್ಸ್ ಪ್ರತಿ ಮೀಟರಿಗೆ) ಮತ್ತು ಸಾವಯವ ಇಂಗಾಲವು ಗಮನಾರ್ಹವಾಗಿ ಬದಲಾಗಿರುವುದಿಲ್ಲ ಎಂದು ಫಲಿತಾಂಶಗಳು ಬಹಿರಂಗಪಡಿಸಿದವು. ಆದಾಗ್ಯೂ, ಜೈವಿಕ ಗುಣಲಕ್ಷಣವಾದ ಯೂರಿಯಸ್ ಚಟುವಟಿಕೆ ($22.42 \mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$), ಲಭ್ಯವಿರುವ ಮಣ್ಣಿನ ಪೋಷಕಾಂಶಗಳಾದ ಸಾರಜನಕ (307.25 ಕೆ. ಪ್ರತಿ ಹೆ.), ಗಂಧಕ ಮತ್ತು ಸತು (13.28 ಮತ್ತು 1.23 ಮೀ. ಗ್ರಾಂ ಪ್ರತಿ ಕೆ.) ಗಮನಾರ್ಹವೆಂದು ದಾಖಲಿಸಲಾಗಿದೆ ಮತ್ತು ಅದೇ ರೀತಿಯಲ್ಲಿ ಸುಲಭವಾಗಿ ಲಭ್ಯವಿರುವ ಪೋಷಕಾಂಶಗಳ ಭಿನ್ನರಾಶಿಗಳು ಗಮನಾರ್ಹ ವ್ಯತ್ಯಾಸವನ್ನು ಹೊಂದಿವೆ. ಶಿಫಾರಸ್ಸಿನ ಶೇ. 75 ಸಾರಜನಕ + 4 ಮಿ.ಲಿ./ಲಿ ನ್ಯಾನೋ ಯೂರಿಯಾ + ಶಿಫಾರಸ್ಸಿನ ಶೇ.25 ಸತುವಿನ ಸಲ್ಫೇಟ್ + 200 ಪಿಪಿಎಂ ನ್ಯಾನೋ ಗಂಧಕ + 500 ಪಿಪಿಎಂ ನ್ಯಾನೋ ಸತುವಿನ ಉಪಚಾರದಲ್ಲಿ ಸಸ್ಯಗಳ ಬೆಳವಣಿಗೆ, ಇಳುವರಿ ಮತ್ತು ಗುಣಮಟ್ಟದ ನಿಯತಾಂಕಗಳಾದ ಸಸ್ಯದ ಎತ್ತರ (212.69 ಸೆ. ಮೀ.), ಹಸಿರು ಎಲೆಗಳ ಸಂಖ್ಯೆ (30.24), ತುಂಬಿದ ಬೀಜಗಳ ಸಂಖ್ಯೆ (943), ಬೀಜ ಮತ್ತು ಒಣ ಗಿಡದ ಇಳುವರಿ (25.10 ಮತ್ತು 45.37 ಕ್ವಿ. ಪ್ರತಿ ಹೆ.), ಪ್ರೋಟೀನ್ ಮತ್ತು ಎಣ್ಣೆಯ ಅಂಶವನ್ನು (ಶೇ. 23.06 ಮತ್ತು 42.61) ಸುಧಾರಿಸಲು ರಸಗೊಬ್ಬರಗಳ ಅತ್ಯುತ್ತಮ ಸಂಯೋಜನೆಯಾಗಿದೆ. ಆದಾಗ್ಯೂ, ಹೆಚ್ಚಿನ ಖರ್ಚು ಮತ್ತು ಆದಾಯದ (3.03) ಅನುಪಾತವು ಶಿಫಾರಸ್ಸಿನ ಶೇ. 75 ಸಾರಜನಕ + 4 ಮಿ.ಲಿ./ಲಿ ನ್ಯಾನೋ ಯೂರಿಯಾ + ಶಿಫಾರಸ್ಸಿನ ಶೇ.50 ಸತುವಿನ ಸಲ್ಫೇಟ್ + 100 ಪಿಪಿಎಂ ನ್ಯಾನೋ ಗಂಧಕ + 250 ಪಿಪಿಎಂ ನ್ಯಾನೋ ಸತುಉಪಚಾರದಲ್ಲಿ ದಾಖಲಿಸಲಾಗಿದೆ.

ಮೇ, ೨೦೨೪

ಮಣ್ಣು ವಿಜ್ಞಾನ ಮತ್ತು ಕೃಷಿ ರಸಾಯನಶಾಸ್ತ್ರ ವಿಭಾಗ

ಕೃಷಿ ವಿಶ್ವವಿದ್ಯಾನಿಲಯ, ಗಾ, ಕೃ, ವಿ, ಕೇ,

ಬೆಂಗಳೂರು-೫೬೦ ೦೬೫

(ಬಿ. ಮಮತ)

ಪ್ರಧಾನ ಮಾರ್ಗದರ್ಶಕರು

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ABBREVIATIONS USED IN THE THESIS

SYMBOL	ABBREVIATION	SYMBOL	ABBREVIATION
FYM	Farm yard manure	AD	Anno Domini
g cc ⁻¹	Gram per cubic centimeter	mg kg ⁻¹	Milligram per kilogram
°C	Degree centigrade	kg ha ⁻¹	kilogram per hectare
%	Per cent	g ha ⁻¹	Gram hectare
Avail.	Available	Exch.	Exchangeable
N	Nitrogen	g	Gram
P	Phosphorus	meq 100 g ⁻¹	Milli equivalent per 100 grams of soil
P ₂ O ₅	Phosphorus pentoxide	q	Quintal
K	Potassium	CR-K	Constant Rate potassium
K ₂ O	Potassium oxide	Na	Sodium
Ca	Calcium	C.V	Coefficient of variance
Mg	Magnesium	t ha ⁻¹	Tonnes per hectare
S	Sulphur	g cc ⁻¹	Gram per cubiccentimeter
Zn	Zinc	Fig.	Figure
Fe	Iron	kg ha ⁻¹	Kilogram per hectare
Mn	Manganese	ha ⁻¹	Per hectare
Cu	Copper	<u>N</u> NH ₄ OAC	Neutral normal ammonium acetate
B	Boron	<i>et al.</i>	Co workers
DTPA	Di-ethylene triamaine penta acetic acid	HWSK	Hot water soluble K
dS m ⁻¹	Deci siemens per meter	EXK	Exchangeable potassium
EC	Electrical conductivity	NEXK	Non-exchangeablepotassium
BD	Bulk density	S. D	Standard deviation
CEC	Cation exchange capacity	r	Correlation coefficient
WSK	Water soluble potassium	OC	Organic Carbon
g kg ⁻¹	Gram per kilogram	MT	Million tonnes
MOP	Muriate of Potash	P=0.05	At 5 per cent probability
c mol (p ⁺) kg ⁻¹		Centi moles of positive charge per kg of soil	

INTRODUCTION

I INTRODUCTION

Sunflower (*Helianthus annus* L.) is a prominent oilseed crop largely cultivated in India. It is one of the ubiquitous oilseed crops of asteraceae (compositae) family and a vital resource of vegetable oil having about 264 species of *Helianthus* genus. The word sunflower is derived from the Greek word 'helios', meaning Sun, and 'anthos' means flower. Commonly, sunflower is known as 'Surajmukhi'. Sunflower is a temperate crop but is also adaptable to cold as well as high temperature conditions. Sunflowers are said to have originated in the southern regions of the United States and Mexico. It was introduced in India in 1969 and for the purpose of commercial cultivation, it started in 1972- 73. In the world, Argentina, Bulgaria, the USSR, Turkey, the USA, Romania, South America, France, Spain and India are the principal sunflower producing countries. Sunflower is an annual, erect and herbacious plant. It is photo and thermo-insensitive crop, short duration and wide range adaptability to different cropping pattern and also for soil and climatic conditions, tolerance of drought, miniml seed rate, higher seed proliferation ratio. Owing to photo-insensitiveness, it can be grown throughout the year. The quantity of sunflower oil represents about 15% of the world production of major vegetable oils.

Sunflower seeds are the most nutritious and healthy seeds. Sunflower seeds have 35-42% oil, 14-19% protein, 21-27% hull, 7-9% soluble sugar, and 30-35% carbs. Sunflower oil has a rich source of linoleic acid (64%), which removes cholesterol deposition in the coronary arteries of the heart, and thus it is suggested that it is good for heart patients. Sunflower seeds contain oleic acid (20%), a spring of vitamins like A, D, E, and B complex, and a sufficient quantity of calcium and iron (Anonymous, 2011). Sunflower oil is also used for the manufacturing of soaps and cosmetics. Sunflower oil is used for cooking purposes and major part in some margarine and shortening products. Sunflower oil cake contains a high amount of quality protein, about 40–44% of which is used as ration for poultry and livestock (Adeleke and Babalola, 2020)

Sunflower is the third vital oilseed crop in the world, adjacent to groundnut and soybean. India is the second largest country over and above the world's largest importer of vegetable oil. In the world, sunflower occupy 26.95 million ha of area, having 49.27 million tonnes of annual throughput and 1830 kg ha⁻¹ annual productivity during 2020-21. The area under sunflower cultivation is 0.22 million ha, with an output of 0.23 million tonnes and a yield of 1023 kg ha⁻¹ (Anonymous, 2021). In India, the largest producing state is Karnataka and has the first rank in the prolificacy of sunflower at about 2714 kg ha⁻¹ followed by Haryana and Telangana. In

Karnataka, the area under sunflower cultivation is 53.93% and production is 46.54% (Anonymous, 2021).

India is facing severe shortage of edible victual oil mainly because of huge demand due to increasing population, living standard and demand from oil industries. This demand can be met by using high yielding varieties, which has a short duration and a wider adaptability to different soil and climatic conditions. In India, there is very little scope for increasing land under oilseed crops. However, productivity can be increased by increasing production per unit area and per unit time. Sunflower is the best choice among the other oilseed crops that suit all these conditions. On the other hand, the low productivity is due to poor seedling vigour, lousy seed setting and a high proportion of cypselas in the centre of the head and on the other side inadequate and imbalanced supply of nutrients.

Nitrogen (N) is a crucial component of plants' metabolic system, providing nutrition and essential physiological functions. Fertilizers play a significant role in improving food production in countries due to their high-yielding and fertiliser-sensitive crop types (Leghari *et al.*, 2016). Nitrogen transformation processes, such as biological nitrogen fixation, humus mineralization, immobilization, nitrification, denitrification and volatilization, occur with applied nitrogen through fertilisers. However, nitrogen management is complex due to these transformation processes, making it challenging to increase nitrogen use efficiency in acidic soil (Grzyb *et al.*, 2021).

Sulphur (S) is crucial for plant growth, as similar in importance to phosphorus. It facilitates in protein synthesis and is imperative for cystine, cysteine and methionine like amino acids. Notably, sulphur significantly impacts crop yield and quality, enhancing flavor, aroma, and cold resistance (Hitsuda *et al.*, 2005). However, sulphur deficiency can significantly reduce both yield and quality, especially in deficient soils. This deficiency is often observed early in plant growth due to easy leaching from the surface soil. Research by Tandon (1986) suggests that even small amounts of sulphur applied to deficient soils can significantly increase oil production. Given the importance to oil in sunflower, sulphur nutrition is particularly critical for this crop. Without sufficient sulphur, carbohydrates are not fully converted into oil, leading to reduced seed output and quality (Hocking *et al.*, 1987).

While major nutrients are crucial, micronutrients like zinc also play a pivotal role in sunflower production. Zinc is vital for plant metabolism, acting as a factor of nearly 200 enzymes and transcription elements. It impacts protein and carbohydrate synthesis, stem and

root growth, and cell defence against reactive oxygen species. Zinc also plays a structural and functional role in numerous enzymes, including alcohol dehydrogenase, superoxide dismutase, carbonic anhydrase, and RNA polymerase. Additionally, it controls the production and toxicity of free radicals, protecting membrane lipids and sulphhydryl groups. Zinc deficiency can lead to reduced biomass production, pollen function, fertilization, and germination (Kaya and Higgs, 2002; Pandey *et al.*, 2006; Cakmak, 2000).

Fertilizer application to acid soils poses setbacks such as nutrient imbalances, aluminum toxicity, reduced nutrient uptake, phosphorus fixation, decreased microbial activity, lower crop yields, erosion risks, and environmental concerns. These issues arise from soil acidity's adverse effects on nutrient availability and plant growth. Mitigating these problems requires strategies like soil pH adjustment, selecting acid-tolerant crop varieties, and precision nutrient management practices. Regular soil testing and analysis are also crucial for tailoring fertilizer applications to acid soils. Proper management practices, including time of application and dosage adjustments, can minimize environmental impact. Balancing crop productivity with responsible soil and environmental stewardship is crucial in agriculture.

Agriculture today focuses on producing high with minimal land, water, and manpower. With a growing world population, the growing interest in developing management practices to ensure good yields. Foliar nutrition, particularly in acidic soil, can help save the sunflower crop from nutrient loss. Advantages of foliar feeding include quick plant response, small nutrient amounts, compensation for soil fixation, root uptake problems, increased yield, and oil content in sunflowers. Foliar fertilization is a complement to soil fertilization, intended for correcting nutrient deficiencies and plant recovery in adverse conditions. (Pumisacho and Sherwood, 2002). It has been conclusively demonstrated that fertilizer contributes significant improvement in productivity of any crop. Supplying chemical fertilizers in the form of nanoparticles has recently received considerable attention. Indeed, nanotechnology has provided the feasibility of exploiting nanoscale or nanostructured materials as fertilizer carriers or controlled-release vectors for the building of so-called “smart fertilizer” as new facilities to enhance nutrient use efficiency and reduce costs of environmental protection (Tarafdar *et al.*, 2011).

Traditional fertilizers, while essential for plant growth, often face challenges related to nutrient leaching, inefficient absorption, and environmental impact. Nano fertilizers, on the other hand, represent a technological leap that leverages nanotechnology to address these issues. By reducing nutrient losses, enhancing nutrient uptake efficiency, and minimizing environmental impact, nano fertilizers play a pivotal role in advancing the sustainability and

productivity of agriculture. This explores the significance of nano fertilizers in the context of improving nutrient uptake and overall efficiency in crop production. As we search into the intricate world of nanotechnology applied to agriculture, it becomes evident that these novel formulations hold the key to ushering in a new era of precision farming, ensuring optimal nutrient utilization, and fostering a more sustainable and resilient food production system.

Nanotechnology plays a pivotal role in agriculture by enabling precise detection and delivery of optimal quantities of nutrients and pesticides, ensuring enhanced productivity while maintaining environmental safety and increasing nutrient use efficiency. This technology can be integrated across the entire agricultural production system, offering comprehensive benefits (Tarafdar *et al.*, 2011). In acidic soils where, conventional fertilizer application can lead to negative consequences such as low mineralization, acidity, reduced nutrient uptake, and diminished microbial populations, nanotechnology provides a solution through foliar application of nano fertilizers. Nanostructured materials at the nanoscale serve as carriers or controlled-release vectors, creating "smart fertilizers" that enhance nutrient use efficiency and reduce environmental protection costs (Doshi *et al.*, 2008). Nanoparticles, with dimensions between 1 and 100 nm, exhibit unique physicochemical properties due to their high surface area to volume ratio, providing novel functions and improvements in physical, chemical, and biological aspects (Lengke *et al.*, 2000).

Nano fertilizers wield a transformative influence on soil, altering its physical structure by enhancing aggregation, porosity, and water retention, mitigating compaction and water scarcity. Chemically, they impact nutrient availability, pH levels, and ion exchange, enabling precise nutrient delivery for optimized plant utilization. The biological aspect sees changes in microbial communities, vital for nutrient cycling and soil health. These interactions hold implications for long-term crop output and ecosystem sustainability. The intricate interplay between nano-sized nutrient carriers and soil components reveals a potential paradigm shift in agricultural practices.

The current state of nanotechnology is one in which there is considerable potential for benefit but also a significant level of ambiguity about associated hazards. There are scraps of data supporting both optimism and pessimism. Pessimism stems from the vast disparity between the volume of research being conducted on the development of materials such as nanoparticles and the related concerns. Policymakers and regulators have a distinctively forward-looking mindset, which contributes to optimism. The unique features of nanoparticles

may result in significantly different environmental fates and behaviours than their bulk counterparts.

Considering these facts and figures, the research work was designed to evaluate the Effect of different levels of Nano Nitrogen, Sulphur and Zinc on soil properties, nutrient dynamics and productivity of Sunflower in acidic soil with the objectives as follows.

Objectives:

1. To know the effect of nano nitrogen, sulphur and zinc on soil physical, chemical and biological properties.
2. To study the effect of nano nitrogen, sulphur and zinc on nutrient dynamics of nitrogen, sulphur and zinc.
3. To examine the effect of nano nitrogen, sulphur and zinc on nutrient concentration, uptake and nutrient use efficiency.
4. To determine the effect of nano nitrogen, sulphur and zinc on growth, yield, quality and production economics of sunflower.

REVIEW OF LITERATURE

II REVIEW OF LITERATURE

Sunflower is one of the most important oilseed crops of India. Among non-traditional oilseed crops, sunflower has greater potential for narrowing up the gap between the supply and demand of edible oil. But sunflower yield in India is far lower than the genetic potential yield of crop due to different factors, such as nutrient imbalance, less irrigation, less plant population and low soil fertility. Among these factors, imbalanced nutrition is one of the major causes of low yield of sunflower in the country. Nitrogen is a crucial component of plants' metabolic system, providing nutrition and essential physiological functions. Zinc is vital for plant metabolism, acting as a component of nearly 200 enzymes and transcription elements. and sugar transportation. Similarly, sulphur is essential to improve yield and oil content. A brief review of work pertaining to the present investigation on **“Effect of different levels of Nano Nitrogen, Sulphur and Zinc on soil properties, nutrient dynamics and productivity of Sunflower in acidic soil”** is comprehensively presented in this chapter on the following subheadings.

- 2.1 Importance of nanotechnology
- 2.2 Nano fertilizers in agriculture
- 2.3 Comparison of conventional and nano fertilizers
- 2.4 Effect of Nano Nitrogen, Sulphur and Zinc on soil physico-chemical, biological properties and nutrients dynamics.
- 2.5 Effect of Nano Nitrogen, Sulphur and Zinc on nutrients dynamics and transformation in soil.
- 2.6 Effect of Nano Nitrogen, Sulphur and Zinc on nutrients delivery.
- 2.7 Effect of Nano Nitrogen, Sulphur and Zinc on nutrient concentration, uptake and nutrient use efficiency
- 2.8 Effect of Nano Nitrogen, Sulphur and Zinc on growth and growth attributes of sunflower and related crops
- 2.9 Effect of Nano Nitrogen, Sulphur and Zinc on yield and yield attributes of sunflower and related crops
- 2.10 Effect of Nano Nitrogen, Sulphur and Zinc on quality parameters of sunflower and related crops
- 2.11 Effect of Nano Nitrogen, Sulphur and Zinc on production economics of sunflower and related crops

2.1 Importance of nanotechnology

The word “Nano” refers to the dimension that measures one-billionth of a metre or one-millionth of a milli-metre (10^{-9}m) and about 80,000 nano-particles can be arranged across a human hair. Ten hydrogen atoms will make one “nano” and 10 “nano” will make a dimension of a protein molecule and 10 such proteins will measure a size of a virus. In other words, each virus particle can be equally divided into 100 nano-particles. For instance, one gram of montmorillonite clay possesses a surface area of $700 \text{ m}^2 \text{ g}^{-1}$ when it is in micro-scale. If the same material is reduced to the nano-dimension, the surface area increased by several fold of $1000 \text{ m}^2 \text{ g}^{-1}$. Consequently, the adsorptive sites available for nutrient exchange increased tremendously (Subramanian and Sharmila, 2012).

Montas and Shirmohammadi (2004) stated that development of prediction models for transport of nanoparticles in soil, and their interaction with soil pollutants, as a function of soil properties, nanoparticle properties and pollutant properties would enable soil scientists and engineers to design highly effective and low-cost soil remediation strategies. The use of nano zero valent iron (ZVI), bimetallic nanoparticle and emulsified zero valent nanoparticle forms the whole sole for both soil and ground water remediation. Also recently developed carbon nanotubes may also prove to be a most effective tool in remedying contaminated wastewater (Li *et al.*, 2011).

Research in the fields of nano-sensors includes various areas like synthesizing new nano-materials with specific detection sites able to recognize certain pollutants, developing new detection methods, to increase the limit of detection of sensors while ensuring a readable electrical signal and miniaturizing the size of the sensor elements while integrating these with larger parts of device. Forzani *et al.* (2005) observed that heavy metal nano-sensor developed for monitoring heavy metals in drinking water.

Coating and cementing of nano and subnano-composites are capable of regulating the release of nutrients from the fertilizer capsule (Liu *et al.*, 2006). Soil solution can be allowed to react with nano-products that will give accurate measurement of availability of nutrients in the soils. Nano-sensors can be used to determine nutrient, moisture and physiological status of plants which assists in taking up appropriate and timely corrective measures. Nano-particles are 'mini-laboratories' that have the potential to precisely monitor temporal and seasonal changes in soil-plant system. Nanosensors detect the availability of nutrients and water

precisely, which is very much essential to achieve the mission of precision agriculture (Subramanian *et al.*, 2007).

Subramanian and Sharmila (2009) stated that nano-fertilizers are capable of releasing nutrients, especially nitrate nitrogen for more than 50 days while nutrient release from conventional fertilizer (urea) ceased to exist beyond 10-12 days and also suggested that nano-fertilizers may be used as a strategy to regulate the smart release of nutrients that commensurate with crop requirement.

Agarwal and Joshi (2010) registered that iron nano-particles are valuable for the treatment of ground water and surface water contaminants such as chlorinated organic compounds like pesticides and polychlorinated biphenyls (PCBs), organic dyes and various other inorganic compounds. Transforming materials to a nano scale changes their physical, chemical and biological characteristics as well as affecting catalytic properties. The chemical and biological activities of most substances increase at nano scale (Mazaherinia *et al.*, 2010).

Datta (2011) reported that nano-clay composites can supply a wide range of nutrients in desirable proportions. Protection of soil health and the environment requires the rapid and sensitive detection of pollutants and pathogens with molecular precision. Soil fertility evaluation is being carried out for the last 60 years with the same set of protocols which may be absolute for the current production systems and in the context of precision farming approaches. Accurate sensors are needed for in-situ detection, as miniaturized portable devices, and as remote sensors, for the real time monitoring of large areas in the field (Subramanian and Tarafdar, 2011). Nanotechnology plays an important role in the development of biosensors (Haruyama, 2003; Jain *et al.*, 2000). Sensitivity and other attributes of biosensors can be improved by using nanomaterials. A biosensor is composed of a biological component, such as a cell, enzyme or antibody, linked to a tiny transducer, a device powered by one system which supplies power (usually in another form) to a second system. The biosensors detect changes in cells and molecules that are then used to measure and identify the test substance, even if there is a very low concentration of the tested material.

Ramesh *et al.* (2011) reported that slow-release fertilizers are excellent alternatives to soluble fertilizers. Nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without waste by leaching. Slow release of nutrients in the environments could be achieved by using ‘zeolites’, a group of naturally occurring minerals having a honeycomb-like layered crystal structure. Its network of interconnected tunnels and

cages can be loaded with nitrogen and potassium, combined with other slowly dissolving ingredients containing phosphorous, calcium and a complete suite of minor and trace nutrients. Zeolite acts as a reservoir for nutrients that is slowly released on demand.

2.2 Nano fertilizers in agriculture

In India, fertilizers, quality seed and irrigation are majorly responsible for enhanced food grain production from 1960 (55 m t) to 2020 (300 m t) coinciding with the rapid increase in fertilizer consumptions from 0.5 m t to 32 m t respectively. It has been demonstrated that fertilizers contribute to the tune of 35-40 per cent of the productivity of any crop (Tarafdar *et al.*, 2012b). Considering its importance of fertilizers, the Government of India is heavily subsidizing the cost of fertilizers particularly urea. This leads to imbalanced fertilization and nutrient deficiency occurrence in some areas and nitrate pollution of ground water occurs due to excessive nitrogen application. Past few decades, use of N, P and K fertilizers have remained constant as 30-35, 18-20 and 35-40 per cent, respectively, leaving a major portion of added fertilizers to accumulate in the soil or enter into aquatic system causing eutrophication (Subramanian *et al.*, 2007). In order to address these issues of imbalanced fertilization, low fertilizer use and its use efficiency, multinutrient deficiencies and decline of soil organic matter, it is important to evolve a Nano based fertilizer formulation with multiple functions.

Nano-fertilizer technology is very novel technique, few reports and patents strongly suggest that there is a huge scope for the formulation of nano-fertilizers. Significant increase in yields has been observed due to foliar application of nanoparticles as fertilizer reported by Tarafdar *et al.* (2012b). Study shown that 640 mg ha⁻¹ foliar application (40 ppm concentration) of nano sulphur resulted in 80 kg ha⁻¹ P equivalent yield of cluster bean and pearl millet under arid environment. Currently, research is on-going to develop nanocomposites to supply all the required essential nutrients in suitable proportion through smart delivery system. Preliminary results suggest that balanced fertilization may be achieved through nanotechnology (Tarafdar *et al.*, 2012a). Nano-composites being anticipated to supply all the nutrients in precise proportions through “smart” delivery systems also need to be examined very closely.

2.3 Comparison of conventional and nano fertilizers

Conventional Fertilizers are generally applied on the crops by either spraying or broadcasting. However, one of the major factors that decide the mode of application is the final concentration of the fertilizers reaching to the plant. In practical scenario, very less

concentration reaches to the targeted site due to leaching of chemicals, drift, runoff, evaporation, hydrolysis by soil moisture, and photolytic and microbial degradation. It has been estimated that around 40–70 % of nitrogen, 80–90 % of phosphorus, and 50–90 % of potassium content of applied fertilizers is lost in the environment and could not reach the plant which causes sustainable and economic losses. (Ombodi and Saigusa, 2000).

Surface coatings of nanomaterials on fertilizer particles hold the material more strongly due to higher surface tension than the conventional surfaces and thus help in controlled release (Santoso *et al.*, 1995).

Tilman *et al.* (2002) reported that excess use of fertilizers and pesticide increases pathogen and pest resistance, reduces soil micro flora, diminishes nitrogen fixation, contributes to bioaccumulation of pesticides, and destroys habitat for birds. Hence, it is very important to optimize the use of chemical fertilization to fulfil the crop nutrient requirements and to minimize the risk of environmental pollution. Accordingly, it can be favourable that other methods of fertilization be also tested and used to provide necessary nutrients for plant growth and yield production, while keeping the soil structure in good shape and the environment clean (Miransari, 2011).

Nanotechnology has provided the feasibility of exploring nanoscale or nanostructured materials as fertilizer carrier or controlled-release vectors for building of the so-called smart fertilizers as new facilities to enhance the nutrient use efficiency and reduce the cost of environmental pollution (Chinnamuthu and Boopati, 2009).

Kottegoda *et al.* (2011) recorded that Urea modified hydroxyapatite nanoparticles that were sequestered in the cavities of *Gliricidia sepium* wood exhibited much slower release profiles in soils of three different pH values (4.2, 5.2, 7) and were releasing >10 mg a day even by day 60, unlike the faster release that was noted for a conventional fertilizer.

Subramanian and Sharmila (2012) have monitored the nutrient release pattern of nano fertilizer formulations carrying fertilizer nitrogen. The data have shown that the nano-clay based fertilizer formulations (zeolite and montmorillonite with a dimension of 30–40 nm) are capable of releasing the nutrients particularly N for a longer period of time (>1,000 h) than conventional fertilizers.

Liu and Lal (2014) developed Ca and hydroxyapatite nanoparticles, which showed 20 and 33% increment in *Glycine max* seed yield in comparison with conventional phosphorus.

Benzon *et al.* (2015) showed that the full recommended rate of conventional and nano fertilizer enhanced the plant height, chlorophyll content, number of reproductive tillers, panicles, and spikelets over the full recommended rate of conventional were 3.6%, 2.72%, 9.10%, 9.10%, and 15.42%, respectively. Similar results were seen in panicle weight (17.4%), total grain weight (unpolished-17.5%, polished-20.7%), total shoot dry weight (15.3%), and harvest index (2.9%).

Nano-fertilizers have small size and large surface area, resulting high number of particles per unit of weight and specific surface area and thus high reactivity that increases the contact of fertilizer with plant and leading to increase in nutrient uptake and fertilizer use efficiency (Herrera *et al.*, 2016). Nevertheless, nano-particles may increase reactive oxygen species (ROS) levels in plants, which causes cytotoxic effects (Miranda-Villagomez *et al.*, 2019).

A study by Al-Juthery *et al.* (2018) examined the impact of various nano-fertilizers on wheat growth and yield. The results showed that Super micro plus nano-fertilizer, combined with tri (N+P+K), di (N+P), (N+K), and (P+K) nano-fertilizer, significantly improved wheat growth and yield parameters compared to traditional fertilizer treatments. The spray foliar increased by 87.77cm, 12.22cm, 58.22 SPAD, 3.17%, 0.66%, and 2.88% in plant height, length of spike, total chlorophyll, N, P, and K concentrations compared to the control treatment. The same treatment also increased grain yield and protein percent by 5.996 Mg/ha and 13.69%, respectively.

Al-uthery and Al-shami (2019) showed that fertigation of nano NPK fertilizers mixture treatment is superior of WUE, NUE, PUE and KUE (26.50 AE kg fresh tubers kg⁻¹ fertilizer, 97.43%, 98.11% and 97.03%) respectively compare to traditional NPK fertilizer (21.43 kg fresh tubers kg⁻¹ fertilizer, 52.27%, 35.02% and 44.04%) respectively. the highest values were recorded from the single nano (P) and (K) (20.51 and 21.61 kg m⁻³) and did not reach the significantly level fertigation of nano (PK) (22.44 kg m⁻³) compare to single nano-nitrogen (23.32 kg m⁻³).

Application of conventional and nano-fertilizers, especially in its combination (NPK + nNPK), were increased the grain yield and milled rice yield. The GY and MRY of Tarom and Shiroudi cultivar in nano-N (nN) and nano-NPK (nNPK) were significantly higher than their conventional forms (N and NPK, respectively) (Valojai *et al.*, 2021).

2.4 Effect of Nano Nitrogen, Sulphur and Zinc on soil physico-chemical, biological properties and nutrients dynamics.

2.4.1 Effect of Nano Nitrogen, Sulphur and Zinc on soil physico-chemical properties.

Kottegoda *et al.* (2011) reported that the urea modified hydroxyl apatite nanoparticles encapsulated wood-based nano-fertilizer has an initial burst and subsequently slow and sustained release of nitrogen for more than 60 days in two acidic soils (pH 4.2 & 5.2) and sandy soils (pH 7).

Collins *et al.* (2012) studied physico-chemical characteristics of nanoparticles (*viz.*, shape, size and surface charge) on soil (*viz.*, pH, ionic strength, organic matter and clay content). They noticed that soil properties will affect physical and chemical processes of NP resulting in dissolution, agglomeration and aggregation. The behaviour of NPs in soil which in turn control their mobility and their bioavailability to soil organisms.

Moshe *et al.* (2012) studied effect of metal oxide nanoparticles (ZnO and Fe₃O₄) on various soil properties. It was found that the nanoparticles did not change the total amount of organic materials in the soil or the total organic carbon in the soil extract. Denaturing Gradient Gel Electrophoresis (DGGE) fingerprinting revealed that nanoparticles affected the soil bacterial community composition, but had little impact on the macroscopic properties of the soil.

The study investigated by Zhong *et al.* (2014) on effects of different nitrogen fertilizer application rates on soil physical and chemical properties and maize yield. The results showed that soil bulk density increased and soil porosity and field capacity decreased with increasing nitrogen application rates. The soil pH also decreased with increasing nitrogen application rates.

Raliya *et al.* (2015) investigated the effect of nanofertilizers on soil pH and nutrient availability. The study found that the application of nanofertilizers significantly decreased soil pH. This is because the nanoparticles release protons into the soil solution, which lowers the pH. The decrease in soil pH was more pronounced with increasing nanoparticle concentration. The study also found that the application of nanofertilizers increased the availability of nitrogen (N), phosphorus (P), and potassium (K) in the soil. This is because the nanoparticles protect the nutrients from degradation and leaching. The increase in nutrient availability was more pronounced with increasing nanoparticle concentration.

Watson *et al.* (2015) studied the effects of soil properties on phytotoxicity and Zn bioavailability from the NPs in an acidic and a calcareous alkaline soil and concluded that in the acid soil, the ZnO NPs caused dose-dependent phytotoxicity while no phototoxicity in calcareous soil showing that ZnO NPs formulations to be used as a soil amendment need to be tuned to soil properties to avoid phytotoxicity.

Zhou *et al.* (2015) observed the effects of different nitrogen fertilizer application rates on soil physical properties and rice yield. The results showed that soil bulk density increased and soil porosity and water infiltration rate decreased with increasing nitrogen application rates. The soil pH also decreased with increasing nitrogen application rates. Rice yield increased with increasing nitrogen application rates up to a certain point, and then decreased with further increases in nitrogen application rates. The optimal nitrogen application rate for rice yield was 240 kg/ha.

Raliya and Singh (2016) conducted a study on the impact of nano-fertilizers on soil physical properties and plant growth. Their findings indicate that nano-fertilizers have the potential to significantly improve soil aggregation, porosity, and water retention, thereby enhancing soil health and plant productivity.

The study by Efthymiadis (2017) investigated the impact of nanofertilizers on soil chemical properties and microbial community in two different soil types. The researchers applied two types of nanofertilizers, a fertilizer granule (FG-N) and a foliar spray (FG-F), to two contrasting soil types, a sandy loam (Lipa CL) and a clay loam (Lipa LC). They evaluated the effects of the nanofertilizers on soil pH, electrical conductivity (EC), total organic carbon (TOC), total nitrogen (TN), available phosphorus (P), exchangeable potassium (K), and microbial community structure using phospholipid fatty acid (PLFA) analysis.

The increase in the content of the available nitrogen in the soil can be attributed nano fertilizer to the traditional source as nano fertilizers have unique chemical and physical properties that are slower to release and have more delivery rules and are more available to meet the demand for plant roots more efficiently than conventional fertilizers through a process Ion exchange and absorption (Jyothi and Hebsur, 2017).

Zambrano-Sevilla (2019) discusses the potential of nanofertilizers to promote sustainable agriculture. The authors highlight the benefits of nanofertilizers, such as improved nutrient use efficiency, reduced environmental impact and enhanced soil health. They also

discuss the impact of nanofertilizers on soil chemical properties, including pH, EC, and nutrient availability.

Sun *et al.* (2020) investigated the effects of different nitrogen fertilizer application rates on crop yield, soil properties, and leaf physiological attributes in banana. The results showed that soil organic matter content, available nitrogen content, and available phosphorus content increased with increasing nitrogen application rates. The soil pH decreased with increasing nitrogen application rates.

2.4.2 Effect of Nano Nitrogen, Sulphur and Zinc on soil biological properties.

Vijendra and Ashok (2009) evaluated the effects of metal nanoparticles like as fullerenes, gold, silver, Zn and others on the plant growth promoting rhizobia (PGPR). Altogether, the study suggested that metal nanoparticle could significantly produce ecotoxicity and killing of phytostimulatory soil bacteria if not applied in optimum dose. Thus, the engineered nanoparticle (ENPs) should be further tested as a possible eco-friendly agent. However, application as foliar mode doesn't have any negative effect on soil microbes.

Wenchao *et al.* (2010) tested both TiO₂ and ZnO of the nanoparticles on production of wheat biomass. The TiO₂ nanoparticles were retained in the soil for long periods and also primarily adhered to cell walls of wheat. The ZnO nanoparticles dissolved in the soil, thereby enhancing the uptake of Zn by wheat. The nanoparticles also induced significant changes in soil enzyme activities, which are bioindicators of soil quality and health. Soil protease, catalase and peroxidase activities were inhibited in the presence of the TiO₂ nanoparticles, urease activity was unaffected. The nanoparticles themselves or their dissolved ions were clearly toxic for the soil ecosystem when applied in excess quantity.

Saharan *et al.* (2012) also discussed the potential of nanofertilizers to improve soil health. Nano-sized particles can interact with soil microorganisms, potentially enhancing microbial activity and nutrient cycling. Additionally, nanofertilizers can modify soil properties, such as aggregation and water retention, further improving soil health and productivity.

Kim *et al.* (2013) investigated effects of CuO and ZnO nanoparticles (NPs) and microparticles (MPs) on soil microbial toxicity, phytotoxicity and bioaccumulation in two crops (*Cucumis sativus* and *Zea mays*) and found that NPs were more toxic than MPs to microbes and plants in the soil ecosystem in very high concentration. They also found that the

soil enzyme activity and plant biomass were inhibited to the greatest extent by CuO NPs than ZnO NPs.

Shen *et al.* (2015) investigated the eco-toxicological effect of ZnO-NPs on soil microorganisms testing respiration, ammonification, dehydrogenase activity, and fluorescent diacetate hydrolase activity in soil. The study revealed that soil type determines the toxicity of ZnO NPs in soil and toxicity was highest in the acid soil, followed by the neutral soil. The toxicity was relatively low in the alkaline soil. The toxicity was not accounted for by the Zn^{2+} released from the ZnO-NPs but due to the direct interaction of ZnO-NPs with biologic targets.

Zhou *et al.* (2015) experimented on effect of zinc sulphate application on soil enzyme activities and microbial community structure. The results showed that zinc sulphate application increased soil urease activity, dehydrogenase activity, and phosphatase activity. Zinc sulphate application also increased the abundance of bacteria and decreased the abundance of fungi. These changes in soil enzyme activities and microbial community structure were attributed to the increased availability of zinc in the soil.

2.5 Effect of Nano Nitrogen, Sulphur and Zinc on nutrients dynamics and transformation in soil.

Zakia *et al.* (2007) investigated the effect of zinc sulphate application on nitrogen and phosphorus transformation in soil. The results showed that zinc sulphate application increased soil microbial biomass and activity, which promoted the mineralization of organic nitrogen and the release of inorganic nitrogen into the soil. Zinc sulphate application also increased soil phosphatase activity, which promoted the release of inorganic phosphorus from soil organic matter.

De Rosa *et al.* (2010) reported that nano-fertilizers, which deliver nutrients to crops encapsulated within nanoparticles. Nano-fertilizers, encapsulated in nanomaterials, can reduce nitrogen loss due to leaching, emissions, and soil microorganisms. They must show sustained nutrient release on demand, preventing premature conversion. A biosensor could be attached to these nano-fertilizers, allowing selective nitrogen release based on time, environmental, and soil conditions. Slow or controlled fertilizer release can improve soil by reducing toxic effects.

Kim *et al.* (2011) revealed that concentration of zinc in the soil treated with zinc nanoparticles were more than that of treated with soluble zinc. This indicated that in soil there

would be better retention of nanoparticles which reduces phototoxicity and increases the reserve of zinc nutrient in the soil.

Zhou *et al.* (2012) studied on effect of zinc sulphate application on zinc transformation and availability in soil. The results showed that zinc sulphate application increased soil zinc content and decreased soil zinc adsorption capacity. Zinc sulphate application also increased soil zinc labile fraction and decreased soil zinc non-labile fraction. These changes in soil zinc transformation and availability were attributed to the increased solubility of zinc sulphate in the soil.

The study investigated by Zhou *et al.* (2013) on effect of zinc sulphate application on zinc transformation and soil enzyme activities in a calcareous soil. Zinc sulphate treatment enhanced soil zinc concentration while decreasing soil zinc adsorption ability, according to the findings. The addition of zinc sulphate boosted soil dehydrogenase, urease, and phosphatase activities. The enhanced availability of zinc in the soil was ascribed to these changes in soil zinc transformation and enzyme activity.

Li *et al.* (2013) conducted an experiment on effects of different nitrogen fertilizer application rates on soil nitrogen transformation in a maize-wheat cropping system. The results revealed that increasing nitrogen application rates increased soil ammonium (NH_4) content, whereas decreasing nitrogen application rates increased soil nitrate (NO_3). The soil NH_4 level was greatest during the early stages of maize development and steadily dropped subsequently. The soil NO_3 level was maximum during the late stage of maize development and steadily reduced subsequently.

Zhou *et al.* (2014) stated on effect of zinc sulphate application on zinc transformation and rice yield in a paddy soil. The results showed that zinc sulphate application increased soil zinc content and decreased soil zinc adsorption capacity. Zinc sulphate application also increased rice zinc uptake and rice yield. These changes in soil zinc transformation and rice yield were attributed to the increased availability of zinc in the soil.

Zhou *et al.* (2014) investigated on the effect of zinc sulphate application on sulphur transformation and mobility in soil. The results showed that zinc sulphate application increased soil sulphate content and leachate sulphate concentration. The increase in soil sulphate content was attributed to the oxidation of elemental sulphur and the hydrolysis of organic sulphur. The

increase in leachate sulphate concentration was attributed to the increased mobility of sulphate in the soil.

Liu *et al.* (2014) studied on effects of different nitrogen fertilizer application rates on soil nitrogen transformation and rice yield. The results showed that soil NH_4^+ content increased with increasing nitrogen application rates, while soil NO_3^- content decreased with increasing nitrogen application rates. The soil NH_4^+ content was highest at the tillering stage of rice and decreased gradually thereafter. The soil NO_3^- content was highest at the jointing stage of rice and decreased gradually thereafter.

The study investigated by Zhang *et al.* (2015) on the effects of different nitrogen fertilizer application rates on soil nitrogen transformation and microbial community structure in a wheat-maize cropping system. The results revealed that increasing nitrogen application rates raised soil NH_4 content, whereas decreasing nitrogen application rates increased soil NO_3 content. The soil NH_4 level was maximum during the wheat jointing stage and steadily dropped subsequently. The soil NO_3 level was maximum during the heading stage of wheat and steadily dropped subsequently. The number of bacteria grew as nitrogen application rates increased, but the amount of fungus reduced as nitrogen application rates increased.

Zhou *et al.* (2016) investigated the effect of zinc sulphate application on zinc transformation and microbial community structure in a loamy soil. Zinc sulphate treatment enhanced soil zinc concentration while decreasing soil zinc adsorption ability, according to the findings. The application of zinc sulphate boosted soil bacterial abundance while decreasing soil fungal abundance. The enhanced availability of zinc in the soil was ascribed to these changes in soil zinc transformation and microbial community structure.

Zhou *et al.* (2016) experimented on effect of zinc sulphate application on soil sulphur transformation and crop yield in a loamy soil. The results showed that zinc sulphate application increased soil sulphate content and crop sulphur uptake. Zinc sulphate application also increased crop yield. These changes in soil sulphur transformation and crop yield were attributed to the increased availability of sulphur in the soil.

Zhou *et al.* (2016) noted the effects of different nitrogen fertilizer application rates on soil nitrogen transformation and crop growth in a loamy soil. The study found that soil NH_4 content increased with nitrogen application rates, with the highest content at flowering and decreasing gradually. Soil denitrification and ammonium volatilization rates also increased with

nitrogen application. Crop growth increased with nitrogen application up to a certain point, then decreased with further increases.

Zhou *et al.* (2017) experimented on effect of zinc sulphate application on zinc transformation and plant growth in a wheat-maize cropping system. The results showed that zinc sulphate application increased soil zinc content and decreased soil zinc adsorption capacity. Zinc sulphate application also increased wheat zinc uptake and wheat yield. These changes in soil zinc transformation and wheat growth were attributed to the increased availability of zinc in the soil.

The study investigated by Zhou *et al.* (2017) on effect of zinc sulphate application on sulphur transformation and greenhouse gas emissions in paddy soil. The results showed that zinc sulphate application increased soil sulphate content and decreased soil methane (CH₄) and nitrous oxide (N₂O) emissions. The decrease in CH₄ emissions was attributed to the increased sulphate content, which inhibited the activity of methanogenic bacteria. The decrease in N₂O emissions was attributed to the decreased soil denitrification rate, which was associated with the increased availability of sulphate.

Qin *et al.* (2017) investigated the effects of different nitrogen fertilizer application rates on soil nitrogen transformation and environmental impact in a rice-wheat cropping system. The study found that nitrogen application rates increased soil NH₄ content, while decreasing it increased soil NO₃ content. The highest levels were observed during the rice tillering stage and jointing stage, with the rate of soil denitrification rising with higher nitrogen application rates. Additionally, soil ammonium volatilization increased with higher nitrogen application rates, and nitrogen leaching loss increased. Consequently, soil greenhouse gas emissions also increased.

Chen *et al.* (2018) conducted a comprehensive study to investigate the effects of nanofertilizers on soil nutrient dynamics and plant growth. The researchers conducted pot experiments and field trials to assess the effect of nano-sized nutrient transporters on soil nutrient availability, absorption, and plant growth characteristics. Because of their small size, high surface area, and nutrient release control, nanofertilizers considerably enhance nutrient availability, particularly for nitrogen, phosphorus, and potassium.

Zhou *et al.* (2018) studied on effect of zinc sulphate application on soil sulphur transformation and environmental impact in a wheat-maize cropping system. The results

showed that zinc sulphate application increased soil sulphate content and decreased soil leaching loss. Zinc sulphate application also decreased soil CH₄ and N₂O emissions. These changes in soil sulphur transformation and environmental impact were attributed to the increased availability of sulphur in the soil.

Liu *et al.* (2022) conducted a comprehensive study on the impact of nanofertilizers on nutrient transformation and plant growth. They investigated the many pathways by which nanofertilizers might alter nutrient availability, absorption, and usage by plants, emphasizing their potential to boost agricultural yield and sustainability. The relevance of nanofertilizer design and application tactics for enhancing nutrient management and plant development was stressed in the review. They also talked about the potential environmental consequences of nanofertilizers and the need for more research to determine their long-term impact on soil ecosystems.

2.6 Effect of Nano Nitrogen, Sulphur and Zinc on nutrients delivery.

Corradini *et al.* (2010) revealed that the use of chitosan nanoparticles as a carrier to explore the potential of chitosan nanoparticles as controlled release for NPK fertilizers through foliar mode of application.

In rice soils, P fertilization decreased Zn uptake by plant. Zn deficiency in the soil or its unavailability to plant significantly decreases crop yield as well as grain Zn concentration. If the soil is slightly deficient in P or Zn, adding one of the nutrients result in the deficiency of the other one, which can be compensated by fertilizing through foliar application (Barben *et al.*, 2011).

Wanyika (2012) studied the prospect of Mesoporous Silica Nanoparticles (MSN) and purified montmorillonite (MMT) for storage and controlled release of fertilizer. About 15.5 % (w/w) of urea was entrapped into the MSN pores and ~21.4 % w/w intercalated into MMT interlayer space. The release process of Urea-loaded Mesoporous Silica Nanoparticles (UMSN) and Urea-loaded Montmorillonite (UMMT) in water and soil indicated a sustained slow-release profile. The findings for soil release studies of UMSN revealed at least fivefold improvement in the release period while MMT retarded the release of urea significantly.

Collins *et al.* (2012) examined the consequences of adding copper and zinc oxide nanoparticles (NPs) to soil in pots. The fate of these NPs as well as changes in the microbial communities was monitored over 162 days. Results showed that both NP types travelled

through the soil matrix at differential rates and Cu NPs retained in the soil matrix at a higher rate compared to ZnO NPs.

Zhao *et al.* (2013) observed that ZnO NPs co-existing with Zn dissolved species were continuously released Zn to the soil solution to replenish the Zn ions or ZnO NPs scavenged by roots compared to soil treated with alginate which promotes the bioaccumulation of Zn in corn plant tissues.

Helaly *et al.* (2014) tested the effect of ZnO nanoparticles in the *in vitro* cultures of banana. Nanoparticles treated soma clones accumulated with more proline, chlorophyll and antioxidant enzymes and developed more dry matter than the control and also regenerated plantlets with well-formed root systems when applied through spraying.

Manikadan and Subramanian (2015) confirmed that NPK nano fertilizers were capable of releasing nitrogen for 40 days, which coincided closely with the crop growth stages regardless of the soil texture variation.

2.7 Effect of Nano Nitrogen, Sulphur and Zinc on nutrient concentration, uptake and nutrient use efficiency

Khanda (1992) observed the superiority of ZnSO₄ over Zn-EDTA in increasing N, P, K and Zn uptake by rice.

Singh and Tiwari (1992) conducted field experiment with chickpea and stated that zinc application resulted an increase in Zn content and decrease in content of P, Fe and Cu.

Singhal and Rattan (1999) reported that soil application of ZnSO₄ and Zn-EDTA with increasing Zn rates from 0 to 10 mg kg⁻¹ increased the zinc uptake by grain and straw of soybean but Zn content and uptake was more with Zn-EDTA.

Sumathi and Koteswara Rao (2007) reported that dose of Nitrogen through fertilizer and foliar spray recorded significantly higher growth parameters in sunflower which was at par with that under supply of 75 per cent Nitrogen with higher efficiency.

Ma *et al.* (2010) revealed that the possible interactions of nanoparticles with higher plants (radish, rape, tomato, lettuce, wheat, cabbage and cucumber) are adsorption to the root surfaces, incorporation into the cell walls and uptake into the cells and all these processes primarily dependent on the physico-chemical properties of nanoparticles.

Fan *et al.* (2012) recorded significantly higher dry biomass of aerial part of rice A₁ (N 215 kg hm⁻² + nano-carbon 1.194 kg hm⁻²), A₂ (N 150.5 kg hm⁻² + nano carbon 0.836 kg hm⁻²) and A₃ (N 107.5 kg hm⁻² + nano carbon 0.597 kg hm⁻²) treatments with 58, 15.7 and 19.3 % compared to B₁ (N 215 kg hm⁻²), B₂ (N 150.5 kg hm⁻²) and B₃ (N 107.5 kg hm⁻²) treatments, respectively. The yield recorded under combined application of N and nano-carbon were higher than those in treatments received only nitrogenous fertilizer. The yield of A₁, A₂ and A₃ treatments were 18.36 per cent, 8.51 per cent and 10.19 per cent higher compared to B₁, B₂ and B₃.

Significant increase in yields has been observed due to foliar application of nano particles as fertilizer. It was shown that 640 mg/ ha foliar application (40 ppm concentration) of nano NPK gave 80 kg ha⁻¹ yield of cluster bean and pearl millet under arid environment. Fertilizers encapsulated in nanoparticles will increase the uptake of nutrients (Tarafdar *et al.*, 2012a).

Burmana *et al.* (2013) conducted an experiment on ten days old seedlings of chickpea (*Cicer arietinum* L.). The seedlings were sprayed with 1.5 or 10 ppm aqueous solution of zinc oxide (ZnO) nanoparticles and their effects were compared with corresponding concentration of zinc sulphate and ZnO of normal size. Maximum promotory response with respect to shoot dry weight was observed in seedlings treated with 1.5 ppm ZnO nanoparticles, whereas at 10 ppm the nanoparticles exerted adverse effects on root growth. However, overall biomass accumulation improved with the ZnO nanoparticles treated seedlings compared to zinc sulphate and ZnO of normal size.

Mahajan *et al.* (2013) reported that among the different nanoparticle suspensions the maximum growth, nutrients concentration and nutrients uptake was found at 50 ppm ZnFeCu-oxide followed by 50 ppm FeO and lowest were at 20 ppm ZnO over control in mungbean crop.

Sedgi *et al.* (2013) reported that significantly higher germination percentage, root length, root fresh and dry weight in soybean crop were noticed when seeds were treated with different concentrations of poly ethylene glycol (PEG) and nano zinc oxide drought stress conditions. Application of nano zinc oxide followed by stress occurrence caused decrease in seed residual fresh and dry weight.

It was found that the seedlings of green gram displayed good growth over control, demonstrating a positive effect of the nanoparticle treatment. The best performance was observed with nano Zn/CuFe-Oxide followed by nano FeO and nano ZnO. Increased absorption of nanoparticles by plant leaves was also detected by inductive coupled plasma / atomic emission spectroscopy (Shailesh *et al.*, 2013).

Nanomaterials based controlled release nutrient formulations were reported recently (Sarkar *et al.*, 2013; Mandal *et al.*, 2015). Nano clay polymeric based controlled release formulation or fertilizers to supply N, P had been attempted (Sarkar *et al.* 2013) and under pot experimentation reported to give promising result. Zincated Nano Clay Polymer Composites (ZNCPC) as controlled releaser Zn formulation was reported to enhance Zn uptake, P uptake in rice and also stimulated soil microbial activities in terms of enhanced soil dehydrogenase, acid and alkaline phosphatase activity (Mandal *et al.*, 2015).

Afshar *et al.* (2014) studied the effects of different spraying concentrations of nano zinc oxide and zinc oxide on wheat crop. Results revealed that nano-compounds are quickly absorbed by plants in large amounts and hence it can be toxic on plants and plant products when it applied at higher concentration

Azamal and Khawaja (2014) reported that fullerene, C60 and carbon nanotubes have been shown to increase the water retaining capacity, biomass and fruit yield in plants up to 118% and fullerene treated bitter melon seeds also increase the phytomedicine contents such as cucurbitacin-B (74%), lycopene (82%), charantin (20%) and insulin (91%). Since as little as 50µg mL⁻¹ of carbon nanotubes increase the tomato production by about 200%, it can be exploited to enhance the agriculture production in future.

Jhanzab *et al.* (2015) carried out the experiment to determine the role of sulphur Nano Particles for improving NUE in wheat. The results showed that the highest S use efficiency (74.3 %) was observed with 25 ppm of SNPs. Further increase in concentration of SNPs was accompanied by significantly reduction in loss and a higher accumulation.

Taheri *et al.* (2015) studied effect of three different physical forms of ZnO particles (ZnO nano colloid, ZnO nanoparticles and micrometric ZnO) on the growth of corn hybrid. These particles were applied through irrigation water. The concentration of nanoparticles in irrigation water was 2 ppm. The results showed that the treatment with ZnO nanoparticles

increased the shoot dry matter and leaf area indices by 63.8 and 69.7 per cent, respectively over the control due the better uptake and assimilation of nutrients.

Mohsen *et al.* (2016) showed that foliar application of zinc nano-chelate with nano-titanium dioxide (2000 ppm) could increase most of the important traits of barley such as thousand grain weight, grain yield, straw yield and harvest index and resulted in sustainable and high crop production with foliar application of nanoparticle.

An experiment was conducted by Badran and Savin (2017) to study the effect of nano fertilizer on morphological response on bitter almond. The nuts were soaked and treated with different concentrations of nano fertilizer, urea and ammonium sulphate @ 0, 25, 50 and 100% and then stratified at 60°C for 8 weeks. The results revealed that, nano fertilizer affected significantly on seed germination at first stages of bitter almond growth. These may be due to the fertilizers increased the absorption of all nutrients as per required for plant growth throughout the period and act as slow release of fertilizer. Therefore, it reduces nitrogen fertilizer lost by leaching and elevates nitrogen utilization efficiency.

A field experiment was conducted by Al-Uthery *et al.* (2019) to study the impact fertigation of Nano NPK fertilizers in NUE and nutrients distribution in soil of potato. The results revealed that application of 40 L of Nano nitrogen fertilizer (25%N), 10 kg of Nano phosphorus fertilizer (25% P) and 20 kg of Nano potassium fertilizer (35% K) is superior treatment that is superior of NUE, PUE and KUE (97.43%, 98.11% and 97.03%) respectively compare to traditional NPK (52.27%, 35.02% and 44.04%) respectively.

Patel *et al.* (2019) obtained that irrigation scheduled at 40 mm CPE significantly improved the yield attributes, pod and haulm yield, quality of groundnut and uptake of nutrients (NPS). Maximum WUE was achieved with irrigation schedule of 50 mm CPE. Sources of nano sulphur had non-significant effect on yield, quality and uptake of nutrients (NPS) by groundnut.

WA Al-juthery *et al.* (2020) conducted a field experiment on potato during autumn season of 2018 in a private farm located in Al-Taliah area – Babylon governorate. The experiment consisted of 12 treatments: separated fertigation of nano-nitrogen (25% N) and urea (46%N). Nitrogen use Efficiency (NUE) varied according to its source Nano nitrogen or urea, (MoUE) and (BUE) according to its combinations. Efficiency of NUE (90.6, 92.9, 94.48 and 96.7) % for nano fertigation and foliar application treatments (N, N +Mo, N + B and N

+ Mo + B), respectively. NUE for urea fertilizer was (40.29, 42.05, 45.26 and 50.52) for fertigation and foliar application treatments (U, U + Mo, U + B and U + Mo + B), respectively.

2.8 To determine the Effect of Nano Nitrogen, Sulphur and Zinc on growth and growth attributes of sunflower and related crops

A four-year field experiment on nitrogen application to sunflower genotypes grown in semiarid conditions was carried out by De Giorgio *et al.* (2007) and it was reported that Sunflower plants were taken at flowering time and their dry weight, leaf area index and total N content were determined. Results revealed that nitrogen supplied through nano scale material has performed better and recorded higher growth attributes compared to convention method of application.

Yadav *et al.* (2009) evaluated a field trial at Rajmata Vijayaraje Scindia Krishi Vishwavidyalaya, Zonal Agricultural Research Station, Morena, Madhya Pradesh to study the effect of irrigation and nutrients levels on productivity and profitability of Sunflower (*Helianthus annuus* L.) and reported that the application RDF (90:45:45 NPK kg ha⁻¹) and foliar applied nutrients significantly increased plant height (93.8 cm) and other attributes.

El-kady *et al.* (2010) conducted two field studies at Sakha Agric. Res. Station in 2006 and 2007 to examine the impact of foliar and soil fertilization on sunflower cultivation. Nitrogen fertilizer rates of 15, 30, and 45 kg N/acre were applied alone or in combination with foliar sprays of urea, a single superphosphate and a combination of micronutrients. The results showed that nitrogen fertilizer rates and foliar spray application significantly impacted vegetative development features at 65 days after planting. As nitrogen rates and micronutrient spraying increased, flowering time was extended, and plant height, stem diameter, and head diameter were significantly increased.

Kumar *et al.* (2013) conducted a trial at Regional Agricultural Research Station, Nandyal, Andhra Pradesh during 2007 and 2009 to study the influence of NPK Fertilization on growth, yield and economics of sunflower (*Helianthus annuus* L.) and reported that higher plant height and number of green leaves were recorded with application of 100% RDF which was at par with 75% RDF.

Rasool *et al.* (2013) carried out a field experiment at the Research farm, Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences and Technology, India, to examine the effects of nitrogen, sulphur, and farmyard manure (FYM) on sunflower growth

and yield (*Helianthus annuus* L.) for two consecutive rainy (*kharif*) seasons in 2009 and 2010. The result indicated that the plant height, leaf area index, dry matter output, capitulum diameter and achenes capitulum⁻¹ were all drastically increased by the application of fertilizer basal dose and foliar application of nutrients.

Nissanaka (2014) confirmed by taking experiment of nano urea on finger millet that Leaf area at vegetative stage, 50% flowering and maturity and dry mater partitioning to the plant parts shows higher significant difference among treatments.

The potential contribution of nano fertilizers in improving growth and development of crops lies on its ability for greater absorbance and high reactivity. Nano fertilizers can enter the plant cells directly through the sieve-like cell wall structures as the particle sizes are smaller than the sizes of cell wall pores (Benzon *et al.*, 2015).

Hafeez *et al.* (2015) reported that soil application of copper nanoparticles (Cu-NPs) at 30 ppm produced significantly higher chlorophyll content (51.37), leaf area (12.79 cm² plant⁻¹), number of spikes/pot (19), number of grains/spike (31), 100 grain weight (6.45 g) and grain yield (13.51 g) of wheat as compared to control (38.43, 6.85 cm² plant⁻¹, 13, 23, 4.08 g, 6.42 g respectively).

Farnia and Omid (2015) showed that use of Zn Nano fertilizer and Nano bio-fertilizer treatment recorded significantly higher (17000 kg ha⁻¹) biomass yield and control treatment had the lowest (11000 kg ha⁻¹) biomass yield in maize. They also studied the comparison of the mean values of the grain yield for interaction between water stress and Zn Nano fertilizer showed that 7-day irrigation period treatment with use of Zn Nano fertilizer had the higher (10.5 t ha⁻¹) grain yield and nano application of Zn Nano fertilizer in 21 day irrigation period treatment recorded lower grain yield (2.7 t ha⁻¹).

Abasalt *et al.* (2015) revealed that application of 400 kg ha⁻¹ K nano fertilizer recorded significantly higher plant height (92 cm) and stem diameter (4 cm) compared to control (77 cm and 3 cm, respectively). Results also showed that application of 300 kg ha⁻¹ K nano fertilizer had the higher number of fruits per plant (38), fruit weight (75 gm), fruit diameter (5.7 cm) and fruit yield (90 t ha⁻¹) of tomato compared to control (23, 62 g, 5 cm, 46 t ha⁻¹ respectively).

Shinde *et al.* (2015) reported that maximum growth parameters and yield (11.53 q ha⁻¹) of sesame was recorded by application of 450 ppm nano S through elemental nano sulphur

than rest of the combinations. However, it was at par with application of 300 ppm nano S (10.85 q ha^{-1}).

Jyothi and Hebsur (2017) studied using both conventional and nano fertilizers at the recommended rate (FRR-CF + FRR-NF) significantly improved various parameters compared to using FRR-CF alone. Exposure to different ZnNP concentrations had notable effects on root and shoot length and mass. The experiment took place in Alestar sunflower fields. Urea foliar application at 5% concentration during the 8-10 leaf stage increased the number of seeds per head by 45% compared to the control and by 28.27% compared to other treatments. Additionally, using 5% urea significantly boosted grain yield by 30.27% compared to the control and by 7.50% compared to the 3% urea treatment.

Dambale *et al.* (2018) carried out a field experiment during *kharif* 2016-17 at Oil Seed Research Station, Latur to study the influence of integrated nutrient management on growth, yield, quality and economics of sunflower (*Helianthus annuus* L.). The result concluded that the application of FYM @ 5 t ha^{-1} + 100% RDF + foliar spray of NPK gives the highest plant height (193.67cm), number of functional leaves (25.08), head diameter (19.75) and stem girth (9.14 cm).

At the Faculty of Agriculture at Benha University in Egypt, lettuce was grown in a field experiment on dense clay soil. The study used biofertilization using vesicular arbuscular mycorrhiza (VAM) and foliar spray of nano-urea. The findings demonstrated that nano-urea treatments particularly the intermediate nano rate—increased all growth metrics, including plant height and weight. The nanotechnology application was practicable and more effective, with NL^{-1} concentrations as low as 2500 mg being superior than NL^{-1} concentrations of 5000 mg in regular urea. (Abdel-Salam *et al.*, 2018).

Oad *et al.* (2018) conducted a field experiment during 2012-13 at Sindh Agriculture University, Tandojam, Pakistan to study the effect of application of foliar application of urea on growth and yield of sunflower. The most effective treatment of foliar application of urea (1%) after 35 days of sowing in addition to recommended soil applied urea (130 kg ha^{-1}) showed promising results with 89.61 % seed germination, 179.65 cm plant height, 5.39 cm stem girth and 22.43 cm head diameter.

Rathnayaka *et al.* (2018) performed an experiment at Rice Research Station, Sammanthurai, Sri Lanka during the season of ‘Yala 2017’ April to July involving the use of

NPK fertilizers and Nano-Nitrogen fertilizer to test the growth attributes and yield of rice cultivar 'Bg 250'. The application of 100% RDF and Nano-Nitrogen fertilizer foliar spray has given the highest growth performance with regard to plant height (57.9cm), number of tillers per plant (6), plant dry weight during the ripening stage (9.9g). Application of 100% Nano-Nitrogen fertilizer has given the highest performance with regarding to yield (2.5 tonnes ha⁻¹).

The experimental study was conducted by Kaleri *et al.* (2019) using a Randomized Complete Block Design (RCBD) with a 4 x 5 m² net plot size (20 m²). The following foliar fertilizer treatments were included in the study: NPK (recommended rates through soil) (T₁), Foliar application of N (T₂), Foliar application of Zn (T₃), Foliar application of B (T₄), Foliar application of N and Zn (T₅), Foliar application of N and B (T₆), Foliar application of Zn and B (T₇), and Foliar application of N, Zn and B (T₈). Nitrogen was applied through Urea (@ 1%); whereas Zn (Chelated 6% Zn) and B (Kera Stop 5% Boron) were applied @ 1.25 L ha⁻¹ and 2.5 L ha⁻¹ respectively. The results showed that foliar application of N, Zn, and B (T₈) was the most effective treatment for increasing plant height, number of leaves (36.83 leaves plant⁻¹), stem girth (12.34 cm) and head diameter (26.25cm) of sunflower.

A study conducted in Khuzestan province, Iran, by Alimohammadi *et al.* (2020) found that the height of sugarcane stems increased with fertilizer application, but no significant difference was found between Urea and Nano-Nitrogen Chelate (NNC). The study also revealed that the application of nano nitrogen fertilizer significantly reduced nitrate leaching and increased sugar production in sugarcane. This suggests that nano fertilizers are valuable for reducing nitrate leaching and improving sugar production.

Al-Jabri *et al.* (2020) conducted an experiment on the impact of pollination with *Azotobacter chroococcum* and *Bacillus subtilis* and nitrogenous manure spraying on the nitrogen and phosphorus concentrations in soil and okra plants. The study was conducted in the summer agricultural season of 2019 on Al-Hasnawi variety in Al-Muthanna Governorate, District Al-Khidr. The experiment used a Randomized Complete Block Design (RCBD) with three replications, with two variables: a biofertilizer with four levels and a nitrogenous fertilizer with four levels. The nano-nitrogen fertiliser spraying significantly increased nitrogen and phosphorus concentration in the fruit, resulting in improved growth, yield, output, and okra quality.

Babita *et al.* (2020) conducted a field experiment on the farmer's field of village Dihakuransa, Block Rasulpur of Jajpur District of Odisha to study the effect of Nano fertilizers

on growth, yield and economics of Tomato variety Arka Rakshak in *Rabi* season of 2019. From the experiment it was observed that application of T₅ i.e., 100% NanoNitrogen (usual TSP and MOP) produced maximum plant height (122.45 cm), number of branches plant⁻¹ (12.4), fruit length (7.15 cm), fruit girth (5.32 cm), maximum number of fruits plant⁻¹ (64.03), individual fruit weight (66.48 g) and highest yield ha⁻¹.

Sharma *et al.* (2022) carried out the field experiment at Research Farm of Vivekananda Global University in Jaipur (India), during the *Kharif* 2021 in titled Effect of Foliar Application of Nano-Urea under Different Nitrogen Levels on Productivity and Quality of Pearl Millet (*Pennisetum glaucum* L.). The experiment included a factorial randomized block design with nine treatments combination and three replications. The results showed that compared to control and foliar spray of Nano-Urea (4 ml/l water) at 30 DAS, foliar spray of Nano-Urea (4 ml/l water) at 45 DAS considerably improved the plant height (166.6 cm) and dry matter accumulation (854 g m⁻²) of pearl millet.

Chandana *et al.* (2021) a field experiment was carried out during spring 2020–2021 in the wetland farms of Tamil Nadu Agricultural University, Coimbatore to investigate the impact of application of foliar nano nutrients (N, Zn, and Cu) on the yield and nutrient uptake by rice at harvest. Three replications of each of the twelve treatments were set up using a randomised complete block design. The findings showed that applying 100% NPK + Nano N during active tillering (T₃) and applying 75% N + 100% PK + Nano N during active tillering (T₄) enhanced grain yield (5512 and 5063 kg ha⁻¹) respectively.

2.9 To determine the Effect of Nano Nitrogen, Sulphur and Zinc on yield and yield attributes of sunflower and related crops

Kacharoo and Kumar (1997) studied on yield attributes and seed yield of Indian mustard (*Brassica juncea* L.) cultivar 'Varuna'. Application of 120 mg nano N and 400 ppm nano S significantly increased the seed yield with the concomitant increase in yield attributes viz., number of siliquae per plant, number of seeds per silique, seed weight per plant and 1000-seed weight. The highest seed yield (2085 kg/ha) was recorded with the combined application of nano N and nano S, followed by nano N (2050 kg/ha), nano S (1920 kg/ha) and control (1850 kg/ha).

Shekhawat and Shivay (2008) carried out a field experiment during spring season of 2005 and 2006 on sunflower (*Helianthus annuus* L.) at New Delhi to study the effect of N

sources (pilled urea and calcium ammonium nitrate). Under north Indian conditions, an application of 80 kg N ha⁻¹ viz. calcium ammonium nitrate, together with 25 kg S ha⁻¹ and 1.50 kg B ha⁻¹, would be sufficient to maintain spring sunflower yield (1.99 tonnes ha⁻¹).

Jat and Ahlawat (2009) conducted an experiment on sandy loam soil of IARI, New Delhi revealed that application of nano sulphur at 350 and 700 ppm, being on par, recorded significant increase in yield and yield attributes of pigeonpea and groundnut, system productivity and total net income over no sulphur.

Sarkar and Malik (2009) during the spring seasons of 2004 and 2005, a field experiment was carried out at Baruipur Farm, Calcutta University, on Entisol to analyse the effect of nitrogen, sulphur and foliar spray of nitrate salts on sunflower (*Helianthus annuus* L.). The physiological growth indicators, yield characteristics and seed yield improved by application of 60 kg N ha⁻¹ up to 120 kg/ha. On Entisol, it was discovered that foliar nutrition with 120 kg N, 60 kg S and 0.5 percent Ca(NO₃)₂ increased sunflower yield during spring season.

El-kady *et al.* (2010) conducted two field studies at Sakha Agricultural Research Station (ARC) in the summers of 2006 and 2007 to examine the impact of foliar and soil fertilization on the growth, yield and constituent parts of sunflower c.v. Nitrogen fertilizer rates of 15, 30, and 45 kg N/acre were applied either alone or in combination with foliar sprays of urea (2%) and a single superphosphate (4%) and a combination of micronutrients (100 ppm Fe + 140 ppm Zn + 120 ppm Mn). The 100-seed weight, seed yield plant⁻¹, and seed yield per acre all significantly increased with nitrogen fertilizer application up to 45 kg N/acre. The highest oil yield/acre was obtained with nitrogen applied at 45 or 30 kg/acre and urea (2%) sprayed on the crop.

Suzer (2010) conducted a field experiment on the effects of nitrogen and plant density on the seed yield and yield components of two dwarf sunflower hybrids (DW-1 and DW-2) and one standard-height sunflower hybrid (Trakya-80). The results of the experiment showed that nitrogen and plant density had significant effects on seed yield and yield components in all three hybrids. The highest seed yields in both dwarf hybrids were obtained with the spacing of 15 × 70 cm (95,230 plants/ha) and also reported that the economically optimal seed yield per hectare was obtained at 50 kg N/ha for DW-1 and at 80 kg N/ha for DW-2 and Trakya-80.

Application of 1200 ppm N ha⁻¹ registered significantly higher seed yield (2108 kg ha⁻¹) and stalk yield (4072 kg ha⁻¹) over corresponding levels of 600 and 900 ppm N ha⁻¹. Among

the nano sulphur treatments, application of 300 ppm S recorded significantly higher seed yield (2048 kg ha⁻¹) and stalk yield (4028 kg ha⁻¹) of sunflower over 0 and 150 ppm nano S (Pavani *et al.*, 2012).

Seghatoleslami *et al.* (2012) conducted a field experiment to study the effect of irrigation and nitrogen level on yield, yield components and some morphological traits of sunflower and reported that increase in N fertilizer level from 0 to 120 kg ha⁻¹, plant height, stem diameter, leaf number, head diameter, seed number/head, 100-seed weight and seed yield significantly increased by 15.6, 14.4, 13.2, 17.1, 24.2, 13 and 49.1%, respectively

Nasim (2012) conducted a field experiment on Effect of Nitrogen on Yield and Oil Quality of Sunflower (*Helianthus annuus* L.) hybrids under Sub Humid Conditions of Pakistan stated that Hysun-38 had maximum grain yield (3389 kg ha⁻¹), while minimum grain yield (3125 kg ha⁻¹) was observed in Hysun-33.

Muhammad and Maqbool (2015) carried out an experiment in the field of Department of Agronomy, University of Agriculture, Faisalabad, Pakistan to determine the effect of foliar-applied nitrogen (no spray, water, and one percent urea) on sunflower (cv. Hysun-33) under normal and water stress condition at reproductive stage. In compared to water spray (1.07 t ha⁻¹) and no spray (1.00 t ha⁻¹), the yield increase with one percent urea spray was up to 1.37 t ha⁻¹. While using one percent urea spray with soil applied nitrogen in both stressed and unstressed conditions led to the highest values of all parameters. In order to supplement soil-applied nitrogen under water stress, foliar application of urea (1%) can be used to produce a good yield.

Jadav *et al.* (2015) conducted a field experiment on medium black calcareous soils during *Kharif* reported that the combined application of sulphur at 400 ppm and potassium at 400 ppm resulted 60.0 and 114.0 per cent higher in seed and stalk yield of sesame, respectively

An experiment was carried out by Graham *et al.* (2017) at two locations over two growing seasons in South Dakota, USA. As urea-ammonium nitrate (UAN), a goal rate of 90 kg ha⁻¹ was applied either at planting or split-applied. Overall, N additions increased yield significantly when compared to a control. In comparison to split-applying N, the urease inhibitor increased grain yield.

Umbarkar *et al.* (2017) found that the application of 300 ppm elemental nano sulphur along with recommended dose (30:60:30 kg ha⁻¹ NPK) of fertilizer (RDF) recorded the higher seed yield (19.9 kg ha⁻¹) of soybean followed by 200 ppm elemental nano sulphur + RDF but

the differences was at par. The lower seed yield (15.1 kg ha^{-1}) was obtained when only RDF was applied.

Astaneh *et al.* (2018) examined the impact of urea and nano-chelated nitrogen fertilizers on wheat plants under drought stress in Iran's Fars province. The study used split-split plots and varying irrigation treatments, with nitrogen treatment being a sub-factor. The results showed that nano-chelated nitrogen fertilizers increased seed yield by 31, 44, and 98% compared to controls. The maximum mean seed yield was achieved with 110 kg ha^{-1} urea and 41 kg ha^{-1} nano fertilizer. The study suggests that substituting nano-chelated nitrogen for urea can increase yield even in drought-stressed conditions and reduce the amount of fertiliser needed.

Dambale *et al.* (2018) carried out a field experiment during *kharif* 2016-17 at Oil Seed Research Station, Latur to study the influence of integrated nutrient management on growth, yield, quality and economics of sunflower (*Helianthus annuus* L.). The highest production values were produced by mineral treatments using bio-N fertilizer. The most effective treatment (Nano 500 ppm with bio-N fertilizer) produced the most significant component yield values, which were 64.4, 27.7, 11249, and 4395 for plant height (cm), oil (percent) and herb fresh and dry weight (kg/acre), respectively.

Hegab *et al.* (2018) at the Balozza Research Station conducted a field experiment in 2017 to examine the effects of nitrogen fertiliser (urea), nano urea and biofertilization (*Azotobacter chroococcum*) on the chemical composition and productivity of sage plant (*Salvia officinalis* L.). The soil was treated with two types of mineral fertilisers: nano urea, urea and biofertilizer (*A. chroococcum*). A split plot design was employed, with three replications for each treatment. Results demonstrated that urea application rates and nano urea concentrations boosted the yield components of sage plants

Oad *et al.* (2018) carried out a field study during 2012-13 at Sindh Agriculture University, Tandojam, Pakistan, to study the foliar urea affects sunflower growth and yield. The most effective treatment of foliar application of urea (1%) after 35 days of sowing in addition to recommended soil applied urea (130 kg ha^{-1}) showed promising results with 68.51 g seed index/1000 seed weight, $2211.90 \text{ kg ha}^{-1}$ seed yield and $1046.75 \text{ kg ha}^{-1}$ oil yield.

An experiment conducted at Rice Research Station, Sammanthurai, Sri Lanka by Rathnayaka *et al.* (2018) during the season of 'Yala 2017' April to July involving the use of

NPK fertilizers and Nano-Nitrogen fertilizer to test the growth attributes and yield of rice cultivar 'Bg 250'. The application of 100% Nano-Nitrogen fertilizer has given the highest growth and yield performance with regard to plant height (57.9cm), number of tillers per plant (6) and plant dry weight during the ripening stage (9.9g). With regarding to yield 100% Nano-Nitrogen fertilizer has given the highest performance (2.8 tonnes ha⁻¹).

Vaghani *et al.* (2018) reported that the significantly higher yield attributes, seed and stalk yield as well as quality parameters of sunflower were obtained by application of elemental sulphur @ 400 ppm. The seed yield increased to the tune of 15.11 per cent with application of 400 ppm S as compared to control.

Al-juthery *et al.* (2019) carried out a field experiment to investigate the influence of foliar application of Nano chelate silicon fertilizes (NSF), Nano chelated potato specific fertilizer (NPS) and Nano chelated complete micro (NCM) on growth and yield of potato variety Riviera. The results showed that tri combination (NS+NPS+NCM) spray treatment was significantly higher followed by the di and single spray combinations. Fresh yield, dry tubers, vegetative yield and biological yield were (42.130, 9.327, 2.901 and 12.228 Mg ha⁻¹) respectively as compared to the control (28.440, 5.453, 2.240, and 7.693 Mg ha⁻¹), respectively.

Al-Saray and Al-Rubaei (2019) conducted a field experiment to study the effect of nano-nitrogen and organic fertilizer on maize yield and its components. The soil texture was silty clay, and the sub-plot consisted of two levels of nano fertilizer (T1) and two ml of fertilizer per one litre of water (T2). The results showed a substantial difference in yield indicators across the various fertilization treatments, with the Nano fertilizer treatment T2 achieving the highest mean in both spring and autumn seasons. The results showed that nano-nitrogen treatment significantly improved maize yields.

Kaleri *et al.* (2019) conducted an experimental study using a Randomized Complete Block Design with a 4 x 5 m² net plot size (20 m²). The following foliar fertilizer treatments were included in the study: NPK (recommended rates through soil) (T₁), Foliar application of N (T₂), Foliar application of Zn (T₃), Foliar application of B (T₄), Foliar application of N and Zn (T₅), Foliar application of N and B (T₆), Foliar application of Zn and B (T₇), and Foliar application of N, Zn and B (T₈). Nitrogen was applied through Urea (@ 1%). The results

showed that foliar application of N, Zn and B (T₈) was the most effective treatment for increasing sunflower seed yield (2228 Kg ha⁻¹).

Merghany *et al.* (2019) conducted an experiment on cucumber development and fruit yield using Nano fertilizers. They used different concentrations of liquid nano NPK in a plastic greenhouse at Cairo University's faculty of agriculture. The results showed that the nanofertilizer treatments significantly improved cucumber growth and yield. Plant height and leaf count increased after 6 ml of nanofertilizer, while the treatment with 6 ml of NPK improved yield by 4.84 percent and 53.42 percent, respectively. The study highlights the potential of nanofertilizers in improving cucumber growth and yield.

Sarvari *et al.* (2019) carried out a field experiment at the National Agricultural Science and Technology University's research farm in Kandahar, Afghanistan during the summer season of 2017 to determine how foliar nitrogen spray affected sunflower growth, productivity and economics of sunflower (*Helianthus annuus* L.). On the sandy clay loam soil, 12 treatments were set up using a randomized block design and three replications. The results indicated that highest seed production (2,461 kg/ha) was obtained when 50 kg N was applied as a basal + 1.5 percent urea foliar spray at 20 and 40 days after sowing (DAS).

A study conducted by Alimohammadi *et al.* (2020) in Khuzestan Province, Iran, found that the height of sugarcane stems increased with fertilizer application rates, but no significant difference was found between the two types. The yield of sugarcane increased significantly with fertilizer application, but no significant difference was found in sugar content. The study found that the application of Nano nitrogen fertilizer significantly reduced nitrate leaching and increased sugar production in sugarcane. However, when considering nitrate leaching's impact on human health and the environment, nanofertilizers were valuable. The highest sugarcane yield was 83.2 t ha⁻¹ and 8038.1 t ha⁻¹ sugar yield.

Ahmed and El-Karamity (2020) during the 2018 and 2019 growing seasons, two field experiments were conducted at Mallawi Agricultural Research Station, Minia, ARC, to examine the impact of intercropping with three oil seed crops on the productivity, quality and profitability of maize and the use of various rates of N nano + mineral fertiliser. The result concluded that the maximum grain yields (23.25 and 21.61, respectively) were obtained when groundnut and maize were intercropped and when 25 % nano fertilizer N + 75 % mineral fertiliser N were used. The intercropping pattern of maize and groundnuts, which is composed of 25% nano fertilizer N and 75% mineral fertiliser N, was more beneficial for the farmer.

Babita *et al.* (2020) conducted a field experiment on the farmer's field of village Dihakuransa, Block Rasulpur of Jajpur District of Odisha to study the effect of Nano fertilizers on growth, yield and economics of Tomato variety Arka Rakshak in *Rabi* season 2019. From the experiment it was observed that application of 100% Nano-Nitrogen (usual TSP and MOP) produced maximum individual fruit weight (66.48 g) and highest yield (425.24 q ha⁻¹).

El-Gizawy (2020) conducted two field experiments in 2018 and 2019 at Benha University's Experiment and Research Centre. The study involved three yellow maize hybrids (SC 2055, SC 176, and SC P3737) and their responses to different nitrogen fertilizer rates and Nano-N foliar treatments. The results showed that maize hybrid SC P3737 had the highest plant height, ear length, ear diameter, number of grains per row, ear weight, ear grain weight, and 100-grain weight when applied with nano N foliar treatment. The highest grain yield and forage yield were obtained under these conditions.

Khamis *et al.* (2020) carried out the experiment at the Experimental Farm of the Itay-EL-Baroud Agricultural Research Station. Increasing the level of nitrogen fertilization up to 60 kg/ fad, significantly increased all studied characters. Meanwhile, high seed and oil yields were achieved with short interval (every 12 days) under conventional tillage and nitrogen levels of 40 and 60 kg N/ fad. It is recommended to grow sunflower under conventional tillage practice, with applying irrigation every 12 to 18 days and nitrogen fertilizer at the rate of 45 to 60 kg N/ fad, to obtain highest seed and oil yields.

WA Al-juthery *et al.* (2020) conducted a field experiment on potato, separated fertigation of nano-nitrogen (25% N) and urea (46% N). Nitrogen use efficiency (NUE) varied according to its source Nano nitrogen or urea, MoUE and BUE according to its combinations. Efficiency of NUE (90.6, 92.9, 94.48 and 96.7) % for nano fertigation and foliar application treatments (N, N + Mo, N + B and N + Mo + B), respectively. NUE for urea fertilizer was (40.29, 42.05, 45.26 and 50.52) for fertigation and foliar application treatments (U, U + Mo, U + B and U + Mo + B), respectively. Foliar application treatment (N, N + Mo, N + B and Mo + B) fertilizer resulted in the highest efficiency.

Yogendra *et al.* (2020) revealed that the results of 600 on-farm trials with 8 crops conducted during winter season in different districts of Rajasthan have proved that the quantity of urea being applied by the farmers to supply nitrogen to the crops can be successfully reduced to half. The yields obtained with 50% less nitrogen plus 2 sprays of nano-nitrogen in standing crops gave higher yields than that applied in most of the 8 crops tested in these trials. These

results clearly establish that with application of nano fertilizers, the nutrient use efficiency can be significantly enhanced as revealed by 50 per cent saving of urea through two sprays of Nano N.

Yogendra *et al.* (2020) studied on Nano-N and describes the results of 730 on-farm trials conducted on 12 important crops grown during winter season of 2019-20. Results of 730 field demonstrations conducted in different districts of Uttar Pradesh by IFFCO on farmers' fields with 12 crops proved that with the use of nano-nitrogen (Nano-N), the quantity of urea being applied by the farmers to supply nitrogen to their crops can be successfully reduced to half. The yields obtained with 50% less nitrogen as compared to the N applied under farmers fertilizer practice (FFP) and applying 2 sprays of Nano-N in standing crops gave yields higher than FFP in most of the crops tested in these demonstrations. Wheat Grain yield under T₂ [(FFP-50% N) + 2 sprays of nano-N] was the highest (4,779 kg ha⁻¹) with additional increase of 425 kg ha⁻¹ over FFP, giving 9.76% increase.

Dhaliwal *et al.* (2021) in the experiment, different combinations of recommended dose of fertilizer (RDF) with 0.5% FeSO₄. 7H₂O, 0.5% ZnSO₄. 7H₂O and 1% urea at 45 and 60 days after sowing (DAS) were applied to Indian mustard. Foliar application of micronutrients along with urea enhanced the productivity and quality of the crop. The foliar spray of 0.5 percent FeSO₄. 7H₂O + 0.5 percent ZnSO₄. 7H₂O + 1 percent urea (FZU) at 45 and 60 DAS resulted in the greatest increase in grain (27.8%) and stover (34.47%) yields.

Kiran and Samal (2021) the efficacy and production trials of the nano urea have been done at National Agriculture Research System (NARS), ICAR Research Institutes, State Agriculture Universities and Krishi Vigyan Kendras. Nano urea has been tested for its efficacy on over 11,000 locations (farmer field trials), 94 crops and 20 Indian Council of Agricultural Research (ICAR) institutes and State Agricultural Universities, by which an average 8% yield increase was observed. The above trials established that it could increase crop productivity suitably.

Seyed and Sadati (2021) investigated the influence of conventional and nano-fertilizers on grain yield and quality of two rice cultivars (Tarom and Shiroudi) in 2016 and 2017. Results showed that application of conventional and nano-fertilizers, particular in NPK, nNPK and its combination (NPK + nNPK) increased the grain yield (11.24–149.78% in Tarom and 16.86–95.85% in Shiroudi cultivars) and milled rice yield (25.33– 157.35% in Tarom and 16.05–112.39% in Shiroudi cultivars)

A pot experiment was conducted by Sheoran *et al.* (2021) at Guru Jambheshwar University of Science and Technology Hisar, Haryana to study the Effect of Environmentally Benign Nano-nitrogen, Potassium, Zinc on Growth and Yield Enhancement in *Triticum aestivum*. The result showed that the yield from the nano-2 treatment was 23.87 g per pot, which was significantly higher than the yield from the nano-1 treatment (19.70 g), the nano-3 treatment (16.94 g) and control (4.38 g).

A total of 187 trials with five treatments were conducted by Tiwari *et al.* (2021) on farmers' fields with potatoes in different districts of Uttar Pradesh during *Rabi* 2019–20. The impacts of only two selected treatments, Farmer's Fertilizer Practice (FFP) (T₁) and FFP-50 percent N + 2 Spray of Nano Urea (T₂) on potatoes based on 187 trials, were presented. The outcomes of 187 potato-growing studies on farmers' fields have shown that the amount of urea applied by farmers to feed nitrogen to the crop can be successfully decreased by half. In the majority of these trials, the yields obtained with two sprays of nano-nitrogen on standing crops and yields acquired with 50% less nitrogen than FFP generated yields (52877 kg ha⁻¹) that were higher than FFP.

A total area of 1225 acres and a randomised block design, 160 field demonstrations were undertaken at two locations in Haryana, India by Kumar *et al.* (2022). In the current study, oil seed crops like mustard and sesame were grown in the field alongside cereal crops like wheat and pearl millet using nitrogen and zinc nano fertilizers. It was discovered that by using nitrogen and zinc nano fertilizers combined with organic farming methods, an average yield was recorded that was 5.35 percent higher in wheat 24.24%t higher in sesame, 4.2 percent higher in pearl millet, and 8.4% higher in mustard.

Midde (2022) at Annamalai Nagar, Annamalai University, a field experiment was carried out in 2021 to investigate the Effect of Nano Nitrogen on Growth and Yield Attributes of Rice (*Oryza sativa* L.). The study's findings showed that the treatment of 50% RDN + 50% Nano N (T₇) produced the highest plant height (104.7 cm), number of tillers (348), grain yield (7056 kg ha⁻¹) and straw production (8342 kg ha⁻¹).

Neogi and Das (2022) examined the impact of nitrogen and zinc fertilisers as nanoparticles on potato growth and productivity in inceptisols. The study involved nine treatments and three replications. The results showed that nano fertilisers significantly increased potato plant height, dry matter output, and leaf area index. The highest overall tuber yield was achieved with treatment T₈, which combined 100% RDF of NPK with foliar

application of Nano Nitrogen + Nano Zinc. Foliar applications of nano-N, nano-Zn, and nano-N + nano-Zn increased total tuber yield by 83.13%, 45.87%, and 149.27%, respectively.

Sumai *et al.* (2022) carried out a field experiment at M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Paralakhemundi, Orissa, India to study the growth and productivity of *rabi* maize as influenced by foliar application of urea and nano-urea with three replication and 11 treatments. The study found that the best method for altering the shape, yield characteristics and yield of *rabi* maize was the adoption of 100% RDN + foliar sprays of nano-urea @ 4 ml/L, twice at knee stage and tasseling stage.

2.10 To determine the Effect of Nano Nitrogen, Sulphur and Zinc on quality parameters of sunflower and related crops

Application of 10 kg S ha⁻¹ in sunflower as foliar application at ray floret stage registered significantly higher seed oil content, kernel oil content and oil yield. The per cent increase in oil yield being 9.5 per cent during summer and 11.5 per cent during *kharif* (Krishnamurthy and Mathan, 1996).

Gokhale *et al.* (2005) found that foliar application of 10 kg S ha⁻¹ recorded significantly higher oil content (20.69 %) and protein content (42.20 %) over control. Significantly higher oil content and protein content in soybean were observed due to foliar application of nano elemental sulphur as compared to gypsum and single super superphosphate.

The quality parameters viz., crude protein content (23.96%) oil content (50.7%) and oil yield (299.6 kg ha⁻¹) of sesame recorded significantly higher with the foliar application of 8 kg S ha⁻¹ (Raja *et al.*, 2007).

A field experiment conducted by Bhosale *et al.* (2011) during *Kharif* season at Junagadh reported that the higher seed yield (804 kg ha⁻¹), stalk yield (1146 kg ha⁻¹), oil content (45.46 %) and protein content (28.04 %) of sesame were recorded by application @ 400 ppm nano S followed by application of nano sulphur @ 200 ppm.

Gholinezhad *et al.* (2011) study found that sunflowers sown in 60x30 cm plant × row spacing (55278 plants ha⁻¹ +3% N ha⁻¹ at seed development stage) ranked first in terms of seed yield, with 166.59 cm plant height, 6.82 cm stem girth, 15.67 leaves, 18.19 cm head diameter, 1408.70 seeds head⁻¹, 60.54 g weight of seeds head⁻¹, 53.05 g seed index, and 40.11% oil content. While sunflower performance was better under wider planting densities, improper

plant population led to lower seed yield ha^{-1} . The sunflower crop sown in row $\times$ plant spacing was most effective with maximum seed yield ha^{-1} .

Kadasiddappa *et al.* (2013) carried out a field experiment to study the production potential of sunflower genotypes under varying fertility levels in Andhra Pradesh. Study on sunflower reported that the application of 120:80:40 NPK ha^{-1} significantly increase in the oil percentage (39.98) and application of 90:60:30 NPK kg/ha observed highest oil yield/ha which was 524 kg ha^{-1} , as compared to application of 30:20:10 NPK kg ha^{-1} and 60:40:20 NPK kg ha^{-1} .

Rasool *et al.* (2013) examined the effects of nitrogen, sulphur and farmyard manure (FYM) on growth and yield of sunflower (*Helianthus annuus* L.) for two consecutive rainy seasons (*khariif*) in 2009 and 2010. The result showed that the application of FYM with Nitrogen and sulphur enhanced 1000 seed weight and oil yield by 11% and 5.4%, respectively.

Kundu *et al.* (2017) reported that application of 400 ppm nano S in combination with NPK significantly increased the number of capsule plant⁻¹, number of seeds capsule⁻¹, the seed and straw yields and also beneficial in increasing the oil content and oil yield of sesame.

A study by Singh and Kumar (2017) examined the impact of nano zinc particles on the growth, yield, and quality of sunflowers in a pot experiment at the University of Agricultural Sciences, Dharwad. The researchers applied different nano particles (ZnO and ZnS) and conventional fertilizer ZnSO₄ at 35 and 55 DAS with and without boron at 0.5 % at 40 DAS. The results showed that the foliar application of zinc sulphide at 400 ppm at 35 and 55 DAS and boron at 0.5 % at 40 DAS was the most effective for sunflower growth, yield, and oil content. This treatment also showed higher seed oil content than the nano ZnS at 400 ppm.

Gangadhara *et al.* (2018) noticed that foliar application of sulphur at 8 kg ha^{-1} recorded significantly higher oil content (37.9%), oil yield (7.7 q ha^{-1}) and crude protein (16.6%) in sunflower over control.

Kalaiyaran *et al.* (2019) obtained that maximum oil (49.4%) and protein contents (25.7%) of groundnut by foliar application of 15 kg S ha^{-1} through gypsum which was closely followed by SSP at 10 kg S ha^{-1} .

A field experiment was conducted by Maragatham *et al.* (2019) to study the effect of foliar application of sulphur on growth, yield and quality of sesame (*Sesamum indicum* L.) during *khariif*

season of 2017-18. The results showed that foliar application of 5 kg S ha⁻¹ increased the sesame seed oil content from 47.63 per cent (control) to 49.83 per cent and oil yield (4.03 q ha⁻¹). The highest seed yield (12.93 q ha⁻¹) was obtained with foliar application of 15 kg S ha⁻¹ + 0.5% B.

Sreelatha *et al.* (2019) reported that in case of oil content and oil yield, the treatment receiving 60 kg P₂O₅ ha⁻¹ through SSP + 250 kg gypsum ha⁻¹ as top dressing, 60 kg P₂O₅ through DAP + 250 kg gypsum ha⁻¹ as basal + 10 kg S as foliar application in groundnut recorded higher values and were on par with each other.

Deshmukh *et al.* (2020) revealed that sesame cv. TKG 21 grown with 10 kg S ha⁻¹ as foliar applied produced the highest seed oil (51.34%), oil yield (4.86 q ha⁻¹) and seed protein (28.30 %) compared to control.

Kewat *et al.* (2020) noticed that the highest quality parameters of sesame viz., oil content (51.56%) and iodine value (107.75) were recorded at 15 kg ha⁻¹ sulphur as foliar application at 30 DAS and lower oil content and iodine value (104.63) were noticed in control treatment.

2.11 To determine the Effect of Nano Nitrogen, Sulphur and Zinc on production economics of sunflower and related crops

The Nitrogen Use Efficiency (NUE) and yield of soyabean (*Glycine max*) cv. Williamz in Fars, Iran, were examined in a field experiment by Shaabani and Dehnavi (2017) comparing the effects of various nitrogen levels, bio-fertilizers and nano-nitrogen. Four different N sources and three different N levels (0, 75, and 150 kg/ha) were used in the treatments (*Rhizobium japonicum* [nitrogen fertilizers], nano-nitrogen, nitroxin and control). The result showed that the application of 150 kg N ha⁻¹ with nano-nitrogen resulted in the highest harvest index (77.81%).

Dambale *et al.* (2018) carried out a field experiment during *kharif* season of 2016-17 at Oil Seed Research Station, Latur to study the influence of integrated nutrient management on growth, yield, quality and economics of sunflower (*Helianthus annus* L.). The results concluded that application of 100% RDF + FYM @ 5 t ha⁻¹ gives highest net monetary return (32527) and B:C ratio (1.84).

Sarvari *et al.* (2019) at the National Agricultural Science and Technology University's research farm in Kandahar, Afghanistan, a field experiment was carried out in the summer of

2017 to determine how foliar nitrogen spray affected sunflower growth, productivity and economics (*Helianthus annuus* L.). On the sandy clay loam soil, treatments 12 were set up using a randomized block design and three replications. The application of 50 kg N as a basal + 1.5 percent urea foliar spray at 20 and 40 days after sowing (DAS) resulted in the highest cultivation cost (54,800 AFN/ha), highest gross return (148,516 AFN/ha), highest net return (93,716 AFN/ha), and highest benefit: cost (2.71) ratio.

A study by Ajithkumar *et al.* (2021) conducted at the University of Agricultural Sciences, Raichur, investigated the impact of IFFCO Nano fertiliser on maize growth, grain yield, and managing Turcicum leaf blight disease. The experiment involved three replications of 11 treatments, with the highest B:C of 2.99. The results showed that the treatment T11, which included IFFCO nano N, IFFCO Sagarika, and two sprays, significantly improved growth and yield parameters. The treatment T10, which included IFFCO nano N, nano Zn, and IFFCO Cu, was found to manage a minimum 18.20 percent severity of Turcicum leaf blight disease better.

Rajesh *et al.* (2021) designed a field study in *Rabi* 2020–21 at ICAR-KVK, UAS, Raichur with the aim of determining the impact of foliar sprays of nano N and nano Zn on the growth and yield of the sweet corn crop. The experiment included chemical nano nitrogen, chemical nano zinc and green nano zinc, as well as two suggested fertiliser doses and an absolute control treatment. Result concluded that the application of 75% N, 100% P & K + foliar applications of chemically produced nano N @ 4 ml/l and chemically synthesised nano Zn @ 2 ml/l at 25 and 50 DAS, respectively, the fresh cob yield (158.1 q ha^{-1}) and green fodder yield (214.5 q ha^{-1}) were significantly higher. Additionally, the gross returns ($1,26,503 \text{ ha}^{-1}$), net returns ($77,928 \text{ ha}^{-1}$) and B: C ratio were also much greater (2.60).

Yadav *et al.* (2021) a field experiment was carried out at the Acharya Narendra Deva University of Agriculture & Technology's main experimental station in Kumarganj, Ayodhya (U.P.) during the *Kharif* 2019–20 to study the effects of foliar application of nano-fertilizers on soil health and productivity in transplanted rice (*Oryza sativa* L.). Six treatments were used in the trial. According to the experimental findings, T₆: 50% N & 0% Zn; 100% P & K + 2 sprays of Nano N mixed with Nano Zn & Nano Cu produced the maximum grain yield (57.82 qt ha^{-1}). T₆: 50% N & 0% Zn; 100% P & K + 2 sprays of Nano N combined with Nano Zn & Nano Cu had the highest gross return (Rs. 119841 ha^{-1}), net return (Rs. 64711 ha^{-1}) and benefit cost ratio (2.17) as well.

MATERIAL AND METHODS

III MATERIAL AND METHODS

The research entitled “**Effect of different levels of Nano Nitrogen, Sulphur and Zinc on soil properties, nutrient dynamics and productivity of Sunflower in acidic soil**” was undertaken during the *Kharif* - 2021 and 2022 at All India Co-ordinated Research Project (AICRP) on sunflower ZARS, GKVK, Bengaluru. Details of the materials used and methods adopted during the research are explained in this chapter.

3.1 Nano Fertilizers

The nano fertilizers used in the experiment are nano nitrogen (Nano Urea - 4% N), nano sulphur (Elemental nano sulphur - 98% S) and nano zinc (Nano Zinc-EDTA - 21% Zn). All the nano fertilizer are commercial products and purchased commercially from different companies company, respectively. Based on the concentrations of nutrients in the product, the necessary calculations are made and required amount of nutrients are applied as per the treatments.

3.2 Experimental site

The experiment was conducted in, AICRP on sunflower ZARS, GKVK, Bengaluru. It is located at an altitude of 924 m above MSL at 13° 09' North latitude and 77° 57' East longitudes situated in the Eastern Dry Zone of Karnataka and the initial soil physico-chemical properties are shown in Table 1.

3.3 Climate and weather conditions

The weather data during the cropping season *kharif* 2021 and *kharif* 2022 is obtained from AICRP on sunflower, UAS, GKVK, Bengaluru and presented in Table 3a and 3b, respectively.

3.4 Selection of crop and variety

The sunflower variety KBSH 44 selected for this study. Developed by AICRP (Sunflower) centre, University of Agricultural Sciences, Bengaluru. It has oil content about 36-38 (%), seed average yield 1500-1800 kg ha⁻¹ and potential yield 2200-2800 kg ha⁻¹.

3.5 Experimental details

The experiment was laid out in a Randomized Complete Block Design (RCBD) with fourteen treatments and three replications. Totally 42 plots were randomized with gross plot size of 5.6 m x 4.8 m (26.88 m²). The details of the experiment and treatments are given in Table 2 and Table 4, respectively and the plan of layout is depicted in Fig. 1.

Table 1: Initial physico-chemical properties of the soil of experimental area

Parameters	Value	
	2021	2022
Course Sand (%)	42.44	42.20
Fine Sand (%)	30.06	30.11
Silt (%)	6.23	6.26
Clay (%)	21.18	21.24
Soil textural class	Sandy clay loam	
Bulk density (mg m^{-3})	1.39	1.38
Maximum water holding capacity (%)	30.59	30.92
Soil pH	5.81	5.84
Electrical conductivity (d S m^{-1})	0.11	0.12
Organic carbon (g kg^{-1})	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 ($\text{c mol (p+) kg}^{-1}$)	2.80	3.47
Exchangeable Magnesium ($\text{c mol (p+) kg}^{-1}$)	1.55	1.92
Available Sulphur (mg kg^{-1})	10.16	11.56
DTPA extractable Iron (mg kg^{-1})	7.55	8.10
DTPA extractable Manganese (mg kg^{-1})	4.30	4.56
DTPA extractable Zinc (mg kg^{-1})	0.72	0.90
DTPA extractable Copper (mg kg^{-1})	0.24	0.26
Available Boron (mg kg^{-1})	0.29	0.28

Table 2: Details of experiment

Particulars	Details
Location	ZARS, GKVK, Bengaluru.
Season	<i>Kharif</i> - 2021 and 2022
Crop	Sunflower
Variety	KBSH 44
Fertilizer dose	37.5: 50: 37.5 (N: P ₂ O ₅ : K ₂ O kg ha ⁻¹)
FYM	6.25 t ha ⁻¹
Seed rate	5 kg ha ⁻¹
Design	Randomized Complete Block Design
Number of treatments	14
Number of replications	3
Gross plot size	5.6 m x 4.8 m (26.88 m ²)
Spacing	60 cm x 30 cm
Date of sowing	Season 1: 23-08-2021 Season 2: 26-11-2021
Date of harvest	Season 1: 26-08-2022 Season 2: 28-11-2022
Source of nutrients	Urea, Di-Ammonium Phosphate (DAP), Muriate of Potash (MOP), Farm Yard Manure (FYM), Zinc sulphate 10 kg ha ⁻¹ , Borax 15 kg ha ⁻¹ . Azatobactor 375 g ha ⁻¹

Table 3a: Meteorological data of experimental area during crop season 2021 - at AICRP on sunflower, GKVK, Bengaluru - 560065

Month	Total rainfall (mm)			Mean Temperature (°C)						Mean relative humidity (%)		
				Maximum			Minimum					
	N	A	D	N	A	D	N	A	D	N	A	D
January	1.7	11.4	9.7	27.4	27.1	-0.3	14.0	15.9	1.9	86.0	89.5	3.5
February	9.6	40.0	30.4	30.0	28.6	-1.4	15.4	14.6	-0.8	81.0	87.9	6.9
March	17.6	0.0	-17.6	32.6	32.5	-0.1	18.0	16.9	-1.1	76.0	81.0	5.0
April	61.8	67.0	5.2	33.8	33.5	-0.3	20.5	19.8	-0.7	80.0	78.1	-1.9
May	109.9	19.4	-90.5	33.0	31.5	-1.5	20.5	20.6	0.1	82.0	80.6	-1.4
June	81.1	117.6	36.5	29.5	29.2	-0.3	19.6	19.5	-0.1	86.0	86.0	0.0
July	103.0	171.6	68.6	28.2	28.0	-0.2	19.1	19.1	0.0	88.0	90.0	2.0
August	139.8	115.4	-24.4	27.7	28.4	0.7	18.9	18.8	-0.1	89.0	92.5	3.5
September	183.2	166.8	-16.4	28.2	28.0	-0.2	18.9	19.0	0.1	89.0	92.5	3.5
October	173.0	231.6	58.6	27.9	28.1	0.2	18.3	18.7	0.4	88.0	92.6	4.6
November	61.7	367.4	305.7	27.9	25.9	-2.0	16.6	17.3	0.7	87.0	90.3	3.3
December	12.4	20.2	7.8	26.3	25.9	-0.4	14.7	17.3	2.6	87.0	90.3	3.3
Total/Mean	954.7	1328.4	373.7	29.3	27.1	-2.2	14.7	15.9	1.2	84.9	87.6	2.7

Note: N- Normal meteorological data (mean of 1976-2021), A- Actual meteorological data, D- Deviation from the normal (A-N)

Table 3b: Meteorological data of experimental area during crop season 2022 - at AICRP on sunflower, GKVK, Bengaluru - 560065

Month	Total rainfall (mm)			Mean Temperature (°C)						Mean relative humidity (%)		
				Maximum			Minimum					
	N	A	D	N	A	D	N	A	D	N	A	D
January	1.7	0.6	-1.1	27.5	27.3	-0.2	14.1	14.8	0.7	86	83	-3
February	9.5	0.0	-9.5	29.9	29.3	-0.6	15.5	16	0.5	81	83	2
March	18.3	0.6	-17.7	32.7	32.0	-0.7	18.1	18.3	0.2	77	81	4
April	52.1	64.8	12.7	33.8	33.5	-0.3	20.5	20.1	-0.4	80	82	2
May	105.7	285.2	179.5	33.0	29.5	-3.5	20.5	19.4	-1.1	83	86	3
June	81.5	216.8	135.3	29.5	28.9	-0.6	19.6	19.0	-0.6	87	88	1
July	105.2	149.8	44.6	28.2	27.3	-0.9	19.1	18.7	-0.4	88	90	2
August	127.1	211.4	84.3	27.7	27.4	-0.3	18.9	18.6	-0.3	89	91	2
September	195.4	142.0	-53.4	28.1	27.7	-0.4	18.9	18.5	-0.4	89	90	1
October	162.5	361.0	198.5	27.9	27.0	-0.9	18.3	16.9	-1.4	88	90	2
November	60.7	30.0	-30.7	26.8	26.0	-0.8	16.7	16.6	-0.1	87	87	0
December	12.0	94.6	82.6	26.3	25.8	-0.5	14.7	16.4	1.7	87	89	2
Total/Mean	931.8	1556.0	624.2	27.5	28.5	1.0	17.9	17.8	-0.1	85	87	2

Note: **N**- Normal meteorological data (mean of 1976-2021), **A**- Actual meteorological data, **D**- Deviation from the normal (A-N)

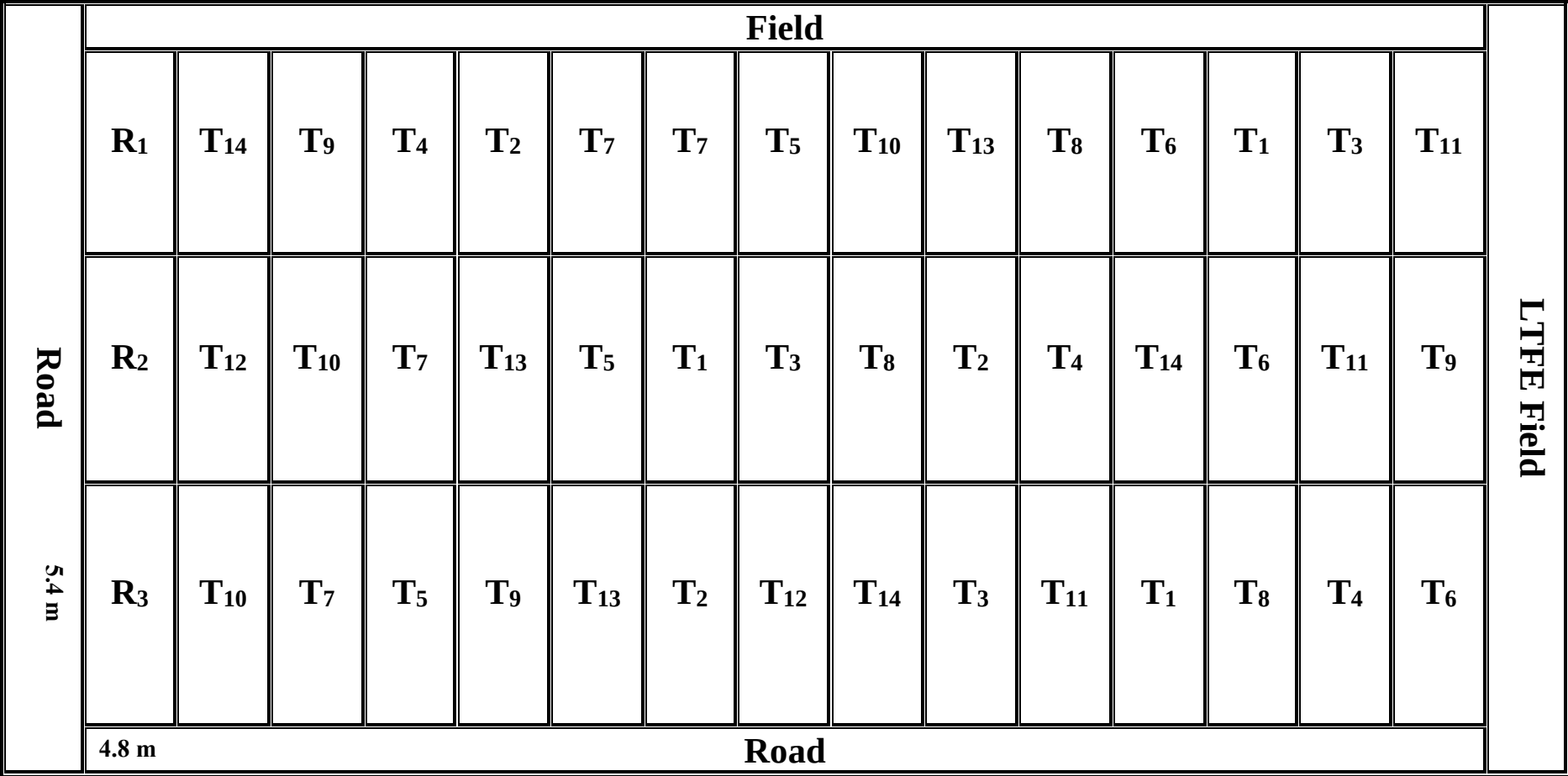


Fig.1: Layout of the experimental plot

Table 4: Treatment details of the experiment

T₁	Absolute control
T₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)
T₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm
T₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm
T₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm
T₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm
T₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm
T₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm
T₁₄	75% RDN + nU @ 4 ml/l + 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.

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

Soil application of FYM two weeks before sowing for respective plots. Required quantities of nitrogen, phosphorus and potassium were thoroughly mixed along with sand to ensure even distribution of fertilizer. 50% of nitrogen, 100% of phosphorus and potassium applied as basal dose, remaining 50% of nitrogen applied at earthing up.

3.6 Crop cultivation

3.6.1 Land preparation

The experimental land was prepared by ploughing once using tractor mounted plough and later by-passing cultivator once for removing weeds and crushing clods, followed by harrowing to bring the soil to fine tilth condition. The land was levelled within the plots for sowing. Later, small channels were created between the replications for drainage.

3.6.2 Application of manures and fertilizers

FYM was applied as per treatments two weeks prior to sowing and mixed thoroughly. Fertilizer nitrogen, phosphorus and potassium were applied through urea, DAP, MOP, zinc sulphate 10 kg ha⁻¹, borax 15 kg ha⁻¹, Azatobactor 375 g ha⁻¹ respectively, as per the treatments. 50 per cent of N and entire dose of P and K were applied at the time of sowing. Remaining, 50 per cent of N was top dressed after one month of sowing in package of practice treatment.

3.6.3 Seeds and sowing

Sowing was carried out first season on 23-08-2021 and second season on 26-08-2022. Bold and quality seeds of sunflower KBSH 44 with a seed rate of 5 kg ha⁻¹ were used for sowing. Seeds are treated with carbendazim at the rate of 2g per kg of seeds to prevent fungal diseases. Seeds were sown in furrows opened at the spacing of 60 cm and dropped at 30 cm distance within the rows at a depth of 2.0 cm. Seeds were smoothly covered with soil immediately to conserve the moisture.

3.6.4 Thinning

Thinning was carried out 15 days after emergence of crop to maintain optimum population with the required spacing and to avoid competition between the seedlings.

3.6.5 Inter-cultivation and weed management

Hoeing was undertaken at 30 days after sowing and weeding operations were carried out twice at 30 and 50 DAS, manually to keep the plots weed free and to provide better root aeration.

3.6.6 Foliar application of nutrients

Treatments were imposed when the crop was at vegetative V4, V6 and ray floret opening stage. Foliar application of different forms and concentrations of nano nitrogen, sulphur and zinc was carried out by taking calculated quantity and dissolved in water to prepare solutions of required concentrations and sprayed to capitulum according to the treatments.



Plate 1: A view of different field operations in production of sunflower

3.6.7 Irrigation

Protective irrigation was given in the absence of rainfall depending upon the soil moisture content and prevailing weather conditions during the period of the experiment. Four protective irrigations were given for the entire crop growth to avoid moisture stress. Two irrigations during the initial growth stage and one each at the grand growth stage and maturity stage, respectively.

3.6.8 Harvesting and Threshing

The crop was harvested at physiological maturity as indicated by lemon yellow colour on the backside of the capitulum, drying of leaves and seeds become hard. The capitulum were harvested separately treatment wise. Threshing was done by beating the capitulum with the stick. The produce was cleaned and net plot seed yield was recorded after thorough drying. The stalks were cut close to the ground and were left in the field for sun-drying and then stalk yield was recorded.

3.7 Observations on growth, yield and quality of sunflower crop:

3.7.1 Growth parameters

3.7.1.1 Plant height (cm)

Plant height was measured from base of the plant to the tip of growing point. Height of the randomly labeled five plants in each plot was recorded at 30 DAS, 60 DAS and at harvest stage. Average value of each plant was worked out, recorded and expressed in centimeter.

3.7.1.2 Number of leaves plant⁻¹

The number of leaves arising from the main shoots were counted from the five tagged plants at 30 DAS, 60 DAS and at harvest. Average value of each plant was recorded and expressed in numbers.

3.7.1.3 Dry matter production (g plant⁻¹)

Three plants were selected at random from each plot. The plants uprooted, air dried initially and then oven dried at 65⁰C till constant weight was obtained and their weights were recorded. Dry mater production was recorded at harvest and expressed as g plant⁻¹.

3.7.1.4 Days to first flowering

The number of days taken for the first flowering of the plant population from each plot from the date of sowing was recorded based on visual assessment and expressed in days.

3.7.1.5 Days to 50 per cent flowering

The number of days taken for maturity was recorded from each plot by the indications such as drying of the leaves, lemon yellow colour on the back side of the capitulum and hardening of seeds.

3.7.1.6 Days to physiological maturity

The number of days taken for maturity was recorded from each plot by the indications such as drying of the leaves, lemon yellow colour on the back side of the capitulum and hardening of seeds.

3.7.2 Yield parameters

3.7.2.1 Number of filled and unfilled seeds per head

Head in the net plot were harvested, seeds were separated by hand threshing, dried and completely filled seed and chaffy seeds per head were separated and counted.

3.7.2.2 Per cent chaffiness

Per cent chaffiness was calculated from five plants from each plot by separating pure and chaffy seeds manually and expressed in percentage.

$$\text{Per cent chaffiness} = \frac{\text{Number of unfilled seeds per head}}{\text{Total number of seeds per head}} \times 100$$

3.7.2.3 100-seed weight (g 100 seeds⁻¹)

Sample seeds from each plot were drawn and 100 medium seeds were counted in an unbiased way manually (regardless of seed size), weighed at 8 per cent moisture and expressed in grams.

3.7.2.4 Seed yield per hectare (kg ha⁻¹)

Head in the net plot were harvested, seeds were separated by hand threshing, dried and weighed at 8 per cent moisture. Seed yield was computed per hectare (kg ha⁻¹) based on the area of each net plot.

3.7.2.5 Stalk yield per hectare (kg ha⁻¹)

Stalks in the net plot were harvested, dried and weighed. Stalk yield was computed per hectare (kg ha⁻¹) based on the area of each net plot.

3.7.3 Quality parameters

3.7.3.1 Crude protein (%)

Crude protein was determined by Kjeldahl's digestion distillation method. Plant samples (0.5 g) were digested in digestion flasks using sulphuric acid and the digestion mixture ($K_2SO_4 + CuSO_4 + Se$ in the ratio of 100:20:1). After complete digestion, the digested materials were distilled in alkaline medium and the liberated ammonia was trapped in four per cent boric acid solution containing mixed indicator. The trapped ammonia was titrated against standard sulphuric acid. The crude protein content was computed by multiplying the per cent nitrogen content with factor 6.25 (Jackson, 1973).

$$\text{Crude Protein (\%)} = \text{Nitrogen content in seeds (\%)} \times 6.25$$

3.7.3.2 Oil Content (%)

Approximately 15 g of seeds drawn randomly from each treatment was oven dried at 550C temperature. The oil and protein contents were estimated by Nuclear Magnetic Resonance (NMR) and kjeldhal estimation respectively. The principle of NMR is that a weighed sample is transferred to a cell and placed in the sample cavity in the magnet unit. After selection of instrument parameters, the instrument automatically sweeps through the resonance condition. Concurrently, the integrator stores information on the amount of energy absorbed by the sample. At the end of the cycle, the total energy absorption is proportional to the amount of mobile hydrogen or oil in the seeds

3.8 Analysis of plant samples

3.8.1 Collection of plant samples

Treatment wise plant samples were collected by uprooting the entire plant carefully. The samples were dried in shade and then oven-dried at 65 °C. Then the plant samples were weighed to record dry matter accumulation in different plant parts and then powdered separately into leaves, stem and reproductive parts with the help of a grinder and stored in butter paper bags. The samples were analyzed for nitrogen, phosphorus, potassium, calcium, magnesium, sulphur, boron, iron, manganese, zinc and copper uptake in seed, leaves and stalk at harvest stage, determined by following standard procedures and expressed as concentration and total uptake of nutrients.

3.8.2 Nitrogen estimation (%)

Grain, leaves and stalk of about 0.5 g of samples were digested with concentrated sulphuric acid (H_2SO_4) and digestion mixture (K_2SO_4 : $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$: selenium in the ratio of 100:20:1). The digested content was distilled by the Macro Kjeldhal. The ammonia produced was trapped in boric acid with mixed indicator and was then measured by titrating against standardized sulphuric acid (Piper, 1966).

3.8.3 Digestion of plant samples for nutrients estimation

One gram of the dried grains, leaves and stalk samples were pre-digested with 10 ml concentrated HNO_3 for 24 hours, then samples were digested with 10 ml di-acid mixture reagent ($\text{HNO}_3 + \text{HClO}_4$ in 9:4) and placed it on a sand bath until white precipitate was left in the bottom. The digested samples were cooled and diluted to 100 ml using distilled water, filtered and used for the analysis of all elements except nitrogen.

3.8.4 Phosphorus (%)

2-5 ml of digested sample was pipetted out into 50 ml volumetric flask. 10 ml of Vanadomolybdate reagent was added and shaken the content and made up the volume. The intensity of yellow color of the solution was read at 420 nm wave length using spectrophotometer (Piper, 1966).

3.8.5 Potassium (%)

The plant samples were tested for potassium content by feeding the di-acid digested samples directly to the flame photometer (Piper, 1966) after diluting it to appropriate concentration.

3.8.6 Calcium and magnesium (%)

Calcium and calcium + magnesium in the di-acid extract were estimated by titrating against standard Versenate solution using Patton Reeders and Eriochrome Black T indicators, respectively. Magnesium content was calculated by subtracting Titrate Value (T.V.) of calcium from Titrate Value of calcium + magnesium (Piper, 1966).

3.8.7 Sulphur (%)

In di-acid digested plant sample, sulphur was determined by using the process called turbidometry. The intensity of turbidity was measured by using spectrophotometer at 420 nm wavelength, as outlined by Piper (1966).

3.8.8 Micronutrient (Fe, Cu, Mn and Zn in mg kg⁻¹)

The di-acid digested plant samples were fed to the atomic absorption spectrophotometer using appropriate hollow cathode lamps to estimate the iron, manganese, zinc and copper concentration in the plant samples (Lindsay and Norwell, 1978).

3.8.9 Boron (mg kg⁻¹)

Boron concentration in di-acid digested sample of plant was estimated by Azomethine-H reagent. The concentration of boron was determined by using spectrophotometer (Page *et al.*, 1982).

3.9 Nutrient uptake

The uptake of nutrients by sunflower crop was calculated after the analysis of nutrients concentrations in sunflower seeds, leaves and stalk. For the calculation of uptake of concentration of each nutrient in seeds, leaves and stalk were multiplied with their respective dry biomass. The formulas below are used to measure the nutrient uptake for macro and micronutrients.

$$\text{Macronutrient uptake (kg ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (\%)} \times \text{Dry Biomass (kg ha}^{-1}\text{)}}{100}$$

$$\text{Micronutrient uptake (g ha}^{-1}\text{)} = \frac{\text{Nutrient concentration (mg kg}^{-1}\text{)} \times \text{Dry Biomass (kg ha}^{-1}\text{)}}{1000}$$

3.10 Nutrient use efficiency (NUE)

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

$$\text{NUE (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot (kg)} - \text{Grain yield of control plot (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

3.11 Collection and processing of soil samples from experimental site

The representative soil samples were collected at plough layer depth (15 cm) from each plot after the harvest of crop. The samples were brought to the laboratory of the Department of Soil Science and Agricultural Chemistry, GKVK, Bengaluru and dried at room temperature. Air dried soil samples were crushed with the help of wooden mortar and pestle and sieved through 2 mm sieve and kept in a polythene bag for analysis of physico-chemical properties of soil using standard methods.

3.12 Methodology for soil analysis

The soil samples collected at initial and at post-harvest were analyzed for physical and chemical properties. The physical properties analysed were bulk density and maximum water holding capacity, chemical properties analysed like available N, P_2O_5 , K_2O ($kg\ ha^{-1}$), exchangeable Ca and Mg ($cmol\ (p+) \ kg^{-1}soil$), available S ($mg\ kg^{-1}$), DTPA extractable Fe, Mn, Zn, Cu ($mg\ kg^{-1}$) and available B ($mg\ kg^{-1}$).

3.12.1 Physical properties of soil

3.12.1.1 Particle size analysis

Distribution of sand, silt and clay in initial soil samples was calculated using an international pipette method as defined in Piper (1966) using sodium hydroxide as a dispersing agent. From the scattered suspension, based on the suspension temperature, an aliquot of clay + silt and clay were pipetted out of the defined depth at their respective time intervals.

The total sand retrieved was transferred into 0.02 mm mesh size sieve through continuous decanting of silt and clay particles. The fraction that was finer than 0.02 mm was added to silt determined initially by pipetting to have particle size classes as per USDA system.

3.12.1.2 Bulk density ($Mg\ m^{-3}$)

The core sampler method (Piper, 1966) was used for determining the bulk density of soil. Metallic core of known volume was driven into the soil and an undisturbed soil sample was taken and then oven dried. The volume was calculated from the core dimension used for driving the sample. Using values of weight and volume bulk density was calculated.

$$BD\ (Mg\ m^{-3}) = \frac{\text{Oven dry weight of soil}}{\text{Volume of soil}}$$

3.12.1.3 Particle density (g/cm³)

A given amount of dry soil when immersed in a definite volume of water, expels air and results in displacement of an equal volume of water. The volume of soil particles is determined by measuring the volume of water displaced in the pycnometer bottle

$$\text{Particle Density (g/cm}^3\text{)} = \frac{\text{Mass of oven dry soil}}{\text{Vol. of the solids excluding pore space}}$$

3.12.1.4 Water stable aggregates (%)

To obtain different size fractions of water-stable aggregates, for the 5 samples from each site, 50 g of soil were placed in the top of a set of sieves with mesh sizes of 5 mm, 2 mm, 1 mm, 0.5 mm, and 0.25 mm from top to bottom. The sieve set was placed on the shock rack of a Yoder aggregates analyzer, submerged in water, and shaken with an amplitude of 3 cm and a frequency of 30 min⁻¹ for a duration of 30 mins. The size fraction at each sieve was then washed into a beaker of known mass and then dried and weighed. The percentage of water-stable aggregate was calculated as

$$\text{WSA (\%)} = 100 \times \frac{\sum W_i}{W}$$

3.12.1.5 Maximum water holding capacity (%) after the harvest of soybean

Keens box method (Piper 1966) was followed for determination of Water Holding Capacity (WHC) of soil samples. In this method weight of empty keen box and filter paper was taken by electronic balance and the weighted filter paper was kept in the keens box followed by filling of keens box tightly with the 2 mm sieved soil. Then the keen box was kept over water up to a mark of its soil level for overnight. On next day the weight of keen box with saturated soil sample was noted and kept in hot air oven for 48 hours at constant temperature of 105 °C. The water holding capacity of soil was determined by the following calculation method.

$$\text{MWHC (\%)} = \frac{(\text{Weight of saturated soil} - \text{Weight of oven dry soil})}{\text{Weight of oven dry soil}} \times 100$$

3.12.2 Chemical properties of soil

3.12.2.1 pH

The soil water suspension (1:2.5) was prepared by taking 20 grams soil in 50 ml distilled water and the suspension was stirred for an interval for 30 minutes and pH was recorded with help of glass electrode pH meter (Jackson, 1973).

3.12.2.2 Electrical conductivity (dS m^{-1})

After recording the pH of the same soil water suspension was kept overnight undisturbed and filtered. Electrical conductivity was measured with the help of electrical conductivity meter (Jackson, 1973).

3.12.2.3 Organic carbon (%)

The soil samples were further pounded using wooden pestle and mortar that were made to pass through 0.2 mm mesh sieve. A 0.5 g of finely ground and powdered sample has been processed with 1N $\text{K}_2\text{Cr}_2\text{O}_7$ (potassium dichromate) and H_2SO_4 acid concentrate. The unused $\text{K}_2\text{Cr}_2\text{O}_7$ was quantified by using ferroin as an indicator in back titrating it against standard Ferrous Ammonium Sulphate (FAS) as described by Walkley and Black (1934).

3.12.2.4 Available nitrogen (kg ha^{-1})

The available nitrogen in soil was determined by alkaline potassium permanganate method as described by Subbaih and Asija (1956). A known weight of soil was treated with excess amount of potassium permanganate with 2.5 % NaOH solution. The liberated ammonia was trapped in 4 % boric acid with mixed indicator solution and determined by titration against standard H_2SO_4 .

3.12.2.5 Available phosphorus (kg ha^{-1})

The available phosphorus from the soil sample was extracted using Bray's No.1 extractant (0.03 N NH_4F + 0.025 N HCl). The phosphorus present in the collected soil sample was measured using a chloro-stannous reduced phospho-molybdenum blue color process in an acid medium containing HCl. The blue color intensity produced in the sample was measured at 660 nm using spectrophotometer (Bray and Kurtz, 1945).

3.12.2.6 Available potassium (kg ha^{-1})

Available potassium was extracted with neutral normal ammonium acetate solution and was determined using flame-photometry as described by Page *et al.* (1982).

3.12.2.7 Exchangeable calcium and magnesium [cmol (p+) kg⁻¹]

The amount of Calcium and Magnesium in the soil sample was measured using Jackson (1973) versenate titration technique.

3.12.2.8 Available sulphur (kg ha⁻¹)

Available sulphur in the soil was extracted from soil by using 0.15 per cent calcium chloride. The sulphur in the extractant was estimated by Turbidometric method using BaCl₂ as stabilizing agent. The turbidity strength produced in the sample was calculated at wavelength of 420 nm using a spectrophotometer as demonstrated by Black (1965).

3.12.2.9 DTPA extractable micronutrients (mg kg⁻¹)

The micronutrients such as Fe, Mn, Zn and Cu was measured using the process of extraction from DTPA (Diethylene Tri Amine Penta acetic acid) established by Lindsay and Norwell (1978). 10 grams of soil for extracting micronutrient cations was continuously shaken with 20 ml of DTPA extractant for 2 hours. To determine the concentration of various micronutrients in the soil sample at their respective wavelengths, atomic absorption spectrophotometer system was used.

3.12.2.10 Available boron (mg kg⁻¹)

Ten grams of soil was taken into 250 ml conical flask 40 ml of distilled water and 0.5 g activated charcoal were added. Boiled for 5 minutes. Filtered immediately, through Whatman no. 40 filter paper. 5 ml of the extract was pipetted out into a 25 mL volumetric flask, 5 mL of buffer solution and 5 mL of Azomethine reagent were added. Kept for one hour for development of color and made up the volume and measured at 420 nm using spectrophotometer (John *et al.*, 1975).

3.12.3 Estimation of biological properties of soil.

3.12.3.1 Microbial biomass carbon and nitrogen

Microbial biomass of carbon and nitrogen were estimated by chloroform fumigation and extraction method as proposed by Carter (1991).

Each soil sample was divided into two sets; one set was fumigated with ethanol free chloroform, while the other set was used unfumigated. Ten gram of each soil sample was fumigated with ethanol - free chloroform for five days in screw-capped tubes. Then the caps were removed and the tubes were kept overnight in an oven at 40°C to remove all the

chloroform. The contents were then extracted with 2M KCl by placing the tubes on a reciprocal shaker for 30 minute and filtered. In a similar manner, unfumigated set of the same soil samples were extracted. Freshly prepared 4 mL of ninhydrin reagent was added to a 2 mL of filtrate and it was boiled in a water bath for 20 minutes. The contents were then allowed to cool and the volume was made up to 10 mL using a 1:1 mixture of methoxy ethanol and distilled water. The intensity of purple colour developed and recorded their intensity using a Bosch and Lamb spectrophotometer at 570 nm wavelength. A standard curve was developed using five different concentrations of L- Leucine N (3.5- 16.8 microgram N ml⁻¹) dissolved in 2M KCl. Absorbance values were compared with the standard curve and the microbial biomass carbon and nitrogen were calculated using the following formulae:

$$\text{Biomass carbon } \mu\text{g g}^{-1} \text{ soil} = \frac{(\text{Ninhydrin reactive N in unfumigated soil}) - (\text{Ninhydrin reactive N in fumigated soil})}{\text{Weight of soil sample (g)}} \times 24$$

$$\text{Biomass nitrogen } \mu\text{g g}^{-1} \text{ soil} = \frac{(\text{Ninhydrin reactive N in unfumigated soil}) - (\text{Ninhydrin reactive N in fumigated soil})}{\text{Weight of soil sample (g)}} \times 2.8$$

3.12.3.2 Dehydrogenase activity

The dehydrogenase activity in the soil samples was determined as described by Casida *et al.* (1964).

Two gram of soil sample was mixed thoroughly with 0.2 g of CaCO₃ and dispensed into test tubes. To each of the sample tube, 1 mL of 2 per cent aqueous solution of 2, 3, 5- triphenyl tetrazolium chloride (TTC) and 2.5 mL of distilled water were added and thoroughly mixed. The tubes were then stoppered using corks and incubated at 37 °C for 24 hours. Later, corks were removed and 10 mL methanol was added to each tube and shaken well. The suspension was filtered through a glass funnel fitted with Whatman No. 15 filter paper into a 50 mL volumetric flask. Each tube was rinsed with methanol. Additional methanol was added to the funnel until the red colour had disappeared. The volume of the filtrate was made up to 50 mL using methanol. The intensity of the red colour was measured using Bosch and Lamb spectrophotometer at a wavelength of 485 nm. The quantity of 2, 3, 5-triphenyl tetrazolium formazan (TPF) was calculated by referring to standard curve, which obtained by absorbance

values of 500, 1000, 1500 and 2000 μg TPF (100 ml for each). The dehydrogenase activities of the samples were expressed as μg TPF formed per gram of sample per 24 hours.

3.12.3.3 Urease activity

The urease activity of the samples was determined by the method given by Eivazi and Tabatabai (1977). Five grams of soil was taken in 125 ml polypropylene bottles and treated with 5 mL of urea solution. Cap the bottles and incubated at 37°C , after five hours removed the caps and added 50 ml 2 M KCl – PMA (Potassium chloride -Phenyl mercuric acetate) solution. Cap the bottles again and kept it on shaker for 1 hour. After shaking, the filtrate was collected under suction through Whatman no-42 filter paper. Pipetted an aliquot (1-2 ml) of the extract containing up to 200 mg per liter of urea in to a 50 ml volumetric flask, made up volume to 10 ml with 2 M KCl – PMA (Potassium chloride -Phenyl mercuric acetate) solution and added 30 ml of the coloring reagent and placed in boiling water bath for 30 min. After that, cool them immediately in cold water for 15 min. and made the volume to 50 ml with distilled water, mixed thoroughly. Measured the absorbance of red colour at 527 nm using spectrophotometer.

Calculated the urea content of the extract analyzed with reference to a calibration graph plotted from the result obtained with standard containing 0, 25, 50, 100, 150 and 200 mg of urea. Expressed the urease activity as μg $\text{NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$.

3.12.3.4 Acid and Alkaline phosphatase activity

Acid Phosphatase activities were estimated as per the procedure described by Eivazi and Tabatabai (1977).

One gram each of the soil samples were taken in wide- mouthed test tubes. To this, 0.2 ml of toluene, 4 ml of modified universal buffer (pH 6.5 for acid phosphatase), and 1 ml of P-nitrophenyl phosphate solution (made in the same buffer) were added. The tubes were swirled for a few seconds to mix the contents and stoppered with cork and placed in incubator at 37°C . After 1 hour, the stoppers were removed and 1 ml of 0.5 M CaCl_2 and 4 ml of 0.5 M NaOH was added. The suspension was centrifuged at 3000 rpm, filtered and the intensity of yellow colour of the supernatant was measured using Bosch and Lamb spectrophotometer at 420 nm wavelength.

The p-nitrophenol (PNP) content of the supernatant was calculated by referring to standard curve obtained with standards containing 0, 10, 20, 30, 40 and 50 μg of P- nitro phenol.

The control was performed in an equivalent manner, but after the addition of 0.5 M CaCl₂ and 0.5 M NaOH, P- nitro phenyl phosphate solution. The phosphatase activities of the samples were then expressed as micrograms of PNP per gram per hour of the sample with respect to the standard curve prepared using graded concentrations of PNP solution

3.12.4 Estimation of nitrogen fractions in soil

3.12.4.1 Total Nitrogen in soil

Total nitrogen was determined by the modified Kjeldhal method (Jackson, 1973).

Digestion

Took 20 g. air-dried soil in the Kjeldahl flask. Wet soil with about 20 ml distilled water and after swirling the flask for a few minutes, allow it to stand for a further 30 minutes. Added 10 g of digestion mixture. Then added 35 ml of conc. H₂SO₄ and swirl it until the acid got mixed with the soil. Set the digestion flask on the digestion stand. Heated the flask cautiously on the digestion stand. Initially heated with low flame for 10-20 minutes until frothing got stopped (when the water has been removed) and then increased the heat until the acid riches boils. Digestion was continued for an hour after the solution has cleared (light yellow or green colour). After completion of digestion, the flask was allowed to cool and about 100 ml of distilled water (slowly and with shaking) to avoid caking of material.

Distillation

Transferred the content of the liquid portion of Kjeldahl to the distillation flask. The flask is placed on a distillation stand. Took 25 ml of 4 % H₃BO₄ in 250 ml beaker and added 3-4 drops of mixed indicator and placed the beaker under condenser in such a way that the tip dipped in the boric acid solution. Added about 100- 150 ml of 10N NaOH solution down the neck. Connected the flask with the condenser by the head and mix the content of the flask carefully by swirling and immediately commenced distillation. Regulated the heating to prevent the suck back of H₃BO₄. Continue the distillation till 150-200 ml of distillate is collected. With the absorption of ammonia, the pinkish color turned green colour.

Titration

The boric acid was b titrated with std. H₂SO₄ till the blue color is just disappeared. Excess of one drop turned the solution pink.

$$\text{Total N \%} = \frac{\text{NR} \times 0.0014 \times 100}{\text{Soil weight in gram}}$$

Soil weight in gram

3.12.4.2 Ammonical nitrogen (NH₄-N) in soil

Ammonical nitrogen was determined by Richardson's method (Richardson, 1938). Exchangeable NH₄⁺ is extracted with 2M KCl (Keeney and Nelson 1982). Weighed 10g soil into a 250 ml Erlenmeyer flask. Added 100ml of 2 M KCl solution and shaken it on mechanical shaker for 1 hour. Filtered the content and it was used for analyse NH₄-N. Added 25 ml of H₃BO₃-indicator solution to 250 ml conical flask and place the flask under the condenser of the steam distillation apparatus, so that the condenser of steam distillation is about 4 cm above the surface of boric acid. Pipetted out 20 ml of the soil extract into a distillation flask, and added 0.2 g MgO, then distillation was carried down. Distillation done about 6-7 minutes. The NH₄-N was estimated through titration of the content in the conical flask with standard H₂SO₄.

$$\text{NH}_4\text{-N (mg/kg soil)} = \frac{V \times 0.02 \times 0.014 \times 100 \times 10^6}{20 \times 10}$$

3.12.4.3 Nitrate nitrogen NO₃-N in soil

Nitrate nitrogen was determined after Olsens extraction for ammonia (Olsen, 1929). After the removal of NH₄-N removed the distillation flask and quickly added 0.2 g Devarda alloy through a dry powder funnel that reaches down into the flask. Start steam distillation immediately and determined NO₃-N as described above for NH₄-N.

3.12.4.4 Nitrite nitrogen NO₃-N in soil

This fraction was determined by taking the difference between the values of (nitrate + nitrite) - N and nitrate-N.

3.12.4.5 Organic Nitrogen in soil

Organic nitrogen was determined by the method described by Fleck and Munro (1965). The analysis starts the acid digestion of the sample organics, converting organic nitrogen to ammonia. This requires boiling the sample in concentrated sulfuric acid, potassium sulfate, and a copper catalyst to convert the organic nitrogen to ammonia. The speed of this reaction is increased by increasing the digestion temperature to 395° C. Therefore, this digestion procedure must be contained within a fume hood. The second part of the method is a repeat of the distillation described above; however, the acidic digestion sample pH must be raised to 9.5 with the addition of concentrated sodium hydroxide. At this pH ammonia gas forms and the gas is transferred by distillation into the acidic trapping/absorbing solution where it is converted back to ammonium. Once again nitrogen concentrations within the receiving solution can then be determined using titrimetric methods.

3.12.5 Estimation of sulphur fractions in soil

3.12.5.1 Total sulphur in soil

The total sulphur was extracted by digesting soil with nitric acid, perchloric acid, and phosphoric acid were added and heated on sand bath at 190-210°C until white fumes were visible. Hydrochloric acid was added after cooling and heated again until white residue was left. The residue was filtered and made to a known volume using 1N HCl. Total sulphur was estimated turbidometrically (Chesnin and Yien, 1951).

3.12.5.2 Sulphur fractions in soil

Soil samples collected after the harvest were analysed for different fractions of sulphur by sequential extraction procedure as outlined by Azmi *et al.*, 2018. After extraction of different fractions, sulphur was estimated turbidometrically (Chesnin and Yien, 1951).

5 g of soil is Leached with 25 ml of distilled water (1:5 soil: water ratio) and it was shaken for about 10 minutes, centrifuged and filtered for water soluble sulphur. Then the soil residue was treated with 25 ml of 0.15% CaCl₂ solution and the content was shaken for half an hour and then centrifuged and filtered for extractable sulphur. Later, 25 ml of 1% HCl solution added to the soil residue, shaken it for 10 minutes, centrifuged and filtered. The soil was then made chloride free by leaching it with distilled water for inorganic sulphur. In the final step, the residue from the HCl extraction (2 g oven dried) was treated with H₂O₂ until the effervescence stops, it was centrifuged and filtered for organic sulphur fraction.

The residual fraction of soil S represents the unaccounted S not extracted by any of the previous sequential extractants, hence, this fraction was calculated from the difference between total S and sum of all fractions.

$$[\text{Total S} - (\text{Water soluble S} + \text{Available S} + \text{Inorganic S} + \text{Organic S})]$$

3.12.6 Estimation of zinc fractions in soils

3.12.6.1 Total zinc in soil

Total zinc was determined by digesting the soil samples with hydrofluoric acid in closed polypropylene bottles. Hundred mg of soil sample was transferred into a 250 ml polypropylene bottle, 2 ml of aquaregia was added to disperse the sample. Later, exactly 10 ml of hydrofluoric acid was added and the contents were shaken to dissolve the sample for a period of 2 to 8 hrs. The residue present after the treatment was dissolved using saturated solution of boric acid and subsequently used for the determination of total Zn by atomic absorption spectrophotometry (Page *et al.*, 1982).

3.12.6.2 Zinc fractions in soil

Zinc in soils was fractionated into different forms designated as water soluble + exchangeable, organically complexed, acid soluble and residual zinc. Each fraction is operationally defined and as described by Murthy (1982) modified by Mandal and Mandal (1986) and Chao (1972).

In the first step of extraction, soil is treated with 1M (NH₄)OAc (pH 7.0) in the ratio of 5:20 and shaken it for 1 hour and filtered it for water soluble and exchangeable zinc fractions and in second step, 0.05 M Cu(OAc)₂ is added in the same ratio, shaken it for 1 hour and filtered it for organically complexed zinc. For the third step, acid soluble fractions like crystalline bound, amorphous bound and manganese oxide bound zinc is extracted using 0.3 M Sodium citrate + 1.0 M NaHCO₃ + 1 g Na₂S₂O₄, 0.2 M (NH₄)₂C₂O₄.H₂O + 0.2 M H₂C₂O₄ (pH 3.0) and 0.1 M NH₂OH.HCl (pH 2.0) respectively. Later in the last step for the estimation of residual zinc, soil is treated with HCl+ conc. HNO₃ in the ratio os 1:8 and all these fractions are determined by Atomic Absorption Spectrophotometer.

The extractions were taken in 50 ml polypropylene centrifuge tubes with suitable weight of soil. Between each successive extraction, the supernatant was obtained by centrifuging for 15 min (3000 rpm) and filtering. The concentration of zinc in the centrifugate was determined by Atomic Absorption Spectrophotometer (Page *et al.*, 1982) and expressed in mg kg⁻¹.

3.13 Economics

Total cost of cultivation was calculated for different inorganic and organic treatments on the basis of cost of inputs used. Gross monetary returns were arrived by multiplying the seed yield with prevailing market price of sunflower seed. Net monetary returns were calculated by deducting the cost of cultivation from gross returns of each treatment.

3.13.1 Gross returns (ha⁻¹)

The gross returns per hectare was calculated by multiplying the prevailing market price (q⁻¹) and total yield (q) obtained per hectare.

$$\text{Gross returns} = \text{market price (q}^{-1}\text{)} \times \text{seed yield (q)}$$

3.13.2 Net returns (ha⁻¹)

The net returns per hectare was calculated by deducting the cost of cultivation per hectare from the gross returns per hectare.

$$\text{Net returns} = \text{Gross returns (ha}^{-1}\text{)} - \text{cost of cultivation (ha}^{-1}\text{)}$$

3.13.3 Benefit cost ratio

The benefit cost ratio was worked out as follows

$$\text{Benefit cost ratio} = \frac{\text{Gross returns}}{\text{Cost of cultivation}}$$

3.14 Statistical analysis

Data was statistically analysed by following the analysis of variance as suggested by Panse and Sukhatme (1978). Critical difference was calculated wherever F test was found significant at 5 percent probability level and the values were furnished. Treatment differences that were non-significant were denoted as “NS”



Plate 2: General view of the experimental field at full flowering stage

RESULTS AND DISCUSSION

V RESULTS AND DISCUSSION

The investigation entitled **“Effect of different levels of nano nitrogen, sulphur and zinc on soil properties, nutrient dynamics and productivity of sunflower in acidic soil.”** was carried out during *Kharif* – 2021 and 2022. The field study was carryout in the field of ZARS, UAS, GKVK, Bangalore - 560065. The data related to the various parameters studied under different objectives were statistically analyzed. Results are described, discussed and graphically presented in this chapter.

4.1 Effect of different levels of nano nitrogen, sulphur and zinc on soil physico-chemical properties

4.2 Effect of different levels of nano nitrogen, sulphur and zinc on soil nutrients status after the harvest of sunflower

4.3 Effect of different levels of nano nitrogen, sulphur and zinc on soil biological properties

4.4 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients dynamics

4.5 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients concentration in sunflower seeds and stalk

4.6 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients uptake and nutrients use efficiency by sunflower

4.7 Effect of different levels of nano nitrogen, sulphur and zinc on growth parameters of sunflower

4.8 Effect of different levels of nano nitrogen, sulphur and zinc on yield parameters of sunflower

4.9 Effect of different levels of nano nitrogen, sulphur and zinc on quality parameters of sunflower

4.10 Effect of different levels of nano nitrogen, sulphur and zinc on economics of production of sunflower

4.1 Effect of different levels of nano nitrogen, sulphur and zinc on soil physico-chemical properties after the harvest of sunflower.

4.1.1 Bulk density (Mg m^{-3})

The data pertaining to bulk density of soil after harvest of sunflower crop as influenced by different levels of nano nitrogen, sulphur and zinc is presented in Table 5. The data indicated that bulk density of the post-harvest soil ranged from 1.33 - 1.38 (Mg m^{-3}). The data reveals that, there was no significant ($p < 0.05$) influence of different levels of nano nitrogen, sulphur and zinc on bulk density of soil. However, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) recorded numerically least bulk density (1.33 Mg m^{-3}) compare to treatment T₁ (1.38 Mg m^{-3}) which is absolute control.

4.1.2 Particle density (g cm^{-3})

Table 5 shows the results on particle density (g cm^{-3}) in soil following sunflower crop harvest as impacted by varied quantities of nano nitrogen, sulphur, and zinc. The findings showed that the particle density of the post-harvest soil was between 2.65-2.67 (g cm^{-3}). The study found no significant ($p < 0.05$) association between nano nitrogen, sulphur, and zinc levels and soil particle density. However, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) had the numerically lowest particle density (2.65 g cm^{-3}) as compared to treatment T₁ (2.67 g cm^{-3}), which was the absolute control.

4.1.3 Water stable aggregates (%)

Table 6 shows the post-harvest water stable aggregates of soil in response to the various quantities of nano nitrogen, sulphur, and zinc applied during sunflower growth. The measured water stable aggregates percentage of the soil after harvest varied from 40.91 to 41.65 per cent. The data show that varying quantities of nano nitrogen, sulfur, and zinc had no significant effect on the water-stable aggregates in the soil. Treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) had the greatest percentage of water stable aggregates (41.65%), whereas treatment T₁, the absolute control, had the lowest percentage of water stable aggregates (40.91%).

4.1.4 Maximum water holding capacity (%)

The data presented in Table 6 pertains to the post-harvest Maximum Water Holding Capacity (MWHC) of soil in relation to different levels of nano nitrogen, sulphur and zinc applied during sunflower cultivation. The recorded MWHC percentage of the soil after harvest ranged from 30.41 to 33.65 per cent. The findings underscore the substantial influence of different levels of nano nitrogen, sulphur and zinc on the soil's MWHC. Notably, the MWHC varied among treatments employing diverse nutrient management strategies. In particular, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) exhibited the highest MWHC percentage at 33.65per cent. Following closely was treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm+ nZn @250ppm) resulting in a MWHC of 33.63per cent in compare with treatment T₁ being absolute control, showed the less MWHC *i.e.*, 30.41per cent.

With the application of different levels of nano nitrogen, sulphur and zinc there was no significant ($p < 0.05$) influence on soil physical properties like bulk density and water holding capacity. However, there was a notable numerical decrease in bulk density and increase water holding capacity was recorded. Soil Organic Matter (SOM) is less dense than mineral soil particles, so its accumulation in the soil leads to a decrease in bulk density. Nitrogen fertilizers stimulate the growth of plants and microbes, which add organic matter to the soil and SOM is very good at holding water. This is because SOM has a large surface area and a high affinity for water molecules. So, as SOM content in the soil increases, its water-holding capacity also increases (Jyothi and Hebsur, 2017). Aggregation is the clumping together of soil particles into larger units. Aggregates are less dense than individual soil particles, so improved aggregation leads to a decrease in bulk density. Nitrogen fertilizers can improve soil aggregation by promoting the growth of plant roots and microbes, which produce sticky substances that bind soil particles together and aggregates have more pores than individual soil particles. These pores can hold water, so improved aggregation leads to an increase in water-holding capacity (Zhao *et al.*, 2013). Nitrogen fertilizers can increase root biomass by stimulating plant growth. Increased root biomass helps to loosen the soil and reduce bulk density and root biomass helps to create channels in the soil that allow water to move and infiltrate more easily. So, increased root biomass can lead to an increase in water-holding

Table 5. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Bulk Density (Mg m^{-3}) and Particle Density (g cm^{-3}) after the harvest of sunflower.

Treatments	Details	Bulk Density (Mg m^{-3})			Particle Density (g cm^{-3})		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	1.38	1.37	1.38	2.67	2.66	2.67
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	1.34	1.33	1.34	2.66	2.65	2.66
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.37	1.35	1.36	2.66	2.65	2.66
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.37	1.36	1.36	2.66	2.65	2.66
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	2.67	2.66	2.67
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	2.66	2.65	2.66
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	2.66	2.65	2.66
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.34	1.33	1.33	2.66	2.65	2.66
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.36	1.36	1.36	2.65	2.65	2.65
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.35	1.34	1.34	2.66	2.65	2.66
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.36	1.35	1.35	2.65	2.65	2.65
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.35	1.34	1.34	2.65	2.65	2.65
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.34	1.32	1.33	2.65	2.65	2.65
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.33	1.33	1.33	2.65	2.65	2.65
	S.Em $\pm$	0.04	0.04	0.04	0.06	0.06	0.06
	CD @ 5%	NS	NS	NS	NS	NS	NS

Table 6. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Water stable aggregates (%) and Maximum Water Holding Capacity (%) after the harvest of sunflower.

Treatments	Details	Water stable aggregates (%)			Maximum Water Holding Capacity (%)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	40.75	41.15	40.95	30.32	30.49	30.41
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	41.12	41.54	41.33	32.51	32.69	32.60
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.09	41.51	41.30	31.04	31.28	31.16
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.19	41.61	41.40	31.26	31.31	31.29
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.24	41.66	41.45	32.32	32.41	32.37
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.31	41.73	41.52	32.98	33.15	33.07
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.38	41.80	41.59	32.64	32.85	32.75
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	41.42	41.84	41.63	33.60	33.65	33.63
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	41.14	41.56	41.35	31.35	31.51	31.43
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	41.22	41.64	41.43	32.67	32.89	32.78
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	41.28	41.70	41.49	32.01	32.24	32.13
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	41.34	41.76	41.55	32.78	32.99	32.89
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	41.39	41.81	41.60	33.10	33.20	33.15
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	41.44	41.86	41.65	33.60	33.70	33.65
	S.Em ±	0.95	0.95	0.95	0.91	0.91	0.91
	CD @ 5%	NS	NS	NS	NS	NS	NS

capacity, especially in sandy soils as depicted by Zhou *et al.* (2015) and Sun *et al.* (2020).

The decrease in bulk density and increase in water-holding capacity of soil with the application of nitrogen fertilizers are generally more pronounced at higher levels of fertilizer application (Raliya and Singh, 2016). This is because higher levels of nitrogen fertilizer stimulate more plant and microbial growth, which leads to greater increases in SOM content, aggregation, root biomass, and other factors that influence bulk density and water-holding capacity as given by Moshe *et al.* (2012). Overall, the application of nitrogen fertilizers can have a beneficial effect on soil bulk density and water-holding capacity. However, it is important to note that excessive nitrogen fertilization can have negative consequences for soil health, such as increased nitrate leaching and nitrous oxide emissions. Therefore, it is important to apply nitrogen fertilizers at recommended rates and in conjunction with other soil management practices that promote good soil health. Similar were outlined by Kim *et al.* (2013), Watson *et al.* (2015) and Collins *et al.* (2012).

4.1.5 Soil pH

The results regarding soil pH following the harvest of sunflower crops under the influence of different levels of nano nitrogen, sulphur and zinc techniques is presented in Table 7. The dataset illustrates that the pH of the soil after harvest ranged from 5.51 to 5.81. The findings suggest that the different levels of nano nitrogen, sulphur and zinc practices did not exert a significant ($p < 0.05$) impact on soil pH. Nonetheless, the treatment T₉ (25% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) exhibited a numerically higher soil pH of 5.81 compared to treatment T₂, which received the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and recorded the lowest soil pH of 5.51.

4.1.6 Electrical Conductivity (E.C.) (dS m⁻¹)

The experimental results information regarding soil Electrical Conductivity (EC) (dS m⁻¹) subsequent to the sunflower crop harvest, influenced by different levels of nano nitrogen, sulphur and zinc practices, is outlined in Table 7. The data unambiguously demonstrate that the different levels of nano nitrogen, sulphur and zinc practices did not exert a significant ($p < 0.05$) impact on the electrical conductivity of the soil after harvest. However, the treatment T₁, representing the absolute control, displayed the lowest numerical value for electrical conductivity (0.10 dS m⁻¹).

This was in contrast to treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)), which exhibited the highest electrical conductivity value (0.17 dS m⁻¹).

4.1.7 Organic Carbon (g kg⁻¹)

Organic carbon levels (g kg⁻¹) in the soil subjected to the different levels of nano nitrogen, sulphur and zinc practices after the sunflower harvest as detailed in Table 7. The dataset indicates a range of 0.51 to 0.57 g kg⁻¹ for organic carbon content in the post-harvest soil. The findings highlight a significant ($p < 0.05$) impact of different levels of nano nitrogen, sulphur and zinc practices on the percentage of soil organic carbon across various treatments following the sunflower harvest. Remarkably, the treatment labelled as T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) recorded the highest organic carbon content at 0.58 g kg⁻¹ in compare to the organic carbon content in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) which recorded value of 0.54 g kg⁻¹.

With the application of different levels of nano nitrogen, sulphur and zinc there was no significant ($p < 0.05$) influence on soil chemical properties like soil pH, electrical conductivity and organic carbon as noted by Raliya *et al.* (2015). However, there was a notable numerical decrease in soil pH and increase in electrical conductivity and organic carbon was recorded. Reasons for decrease in soil pH by application of different levels of nitrogen and zinc sulphate to soil attribute to most nitrogen fertilizers are acidic in nature, meaning that they release hydrogen ions (H⁺) into the soil when they are applied. This can lead to a decrease in soil pH over time and in case of Zinc sulphate, it a neutral salt, but it can still contribute to soil acidification in some cases by the formation of sulphuric acid. For example, if zinc sulphate is applied to a soil that is already acidic, it can further lower the pH (Zong *et al.* (2014) and Shen *et al.* (2015)). Reasons for increases in electrical conductivity (EC) by application of different levels of nitrogen and zinc sulphate are nitrogen fertilizers can increase EC by adding salts to the soil. Salts are ions that dissolve in water, and they can conduct electricity. The higher the concentration of salts in the soil, the higher the EC and zinc sulphate is a salt containing different charged ions, so it will increase EC when it is applied to the soil (Efthymiadis (2017) and Wanyika (2012)). In case of Reasons for increases in organic carbon (OC) by application of different levels of nitrogen and zinc sulphate, Nitrogen fertilizers can increase OC by promoting plant growth (Zambrano-Sevilla (2019) and Watson *et al.* (2015)). Plants absorb nitrogen from the soil, and as they grow, they add organic matter to the soil. This

Table 7. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on pH, Electrical Conductivity (dS m⁻¹) and Organic carbon (%) status of soil after the harvest of sunflower

[illegible]

organic matter decomposes over time, and some of it is converted to OC and Zinc is an essential nutrient for plants, and it is involved in many important plant processes, including photosynthesis and protein synthesis. When plants have enough zinc, they are able to grow more efficiently and produce more biomass. This increased biomass production can lead to an increase in OC as indicated by Helaly *et al.* (2014).

Effects of nitrogen and zinc sulphate fertilizer on soil pH, EC and OC will vary depending on the type of soil, the amount of fertilizer applied and other factors. sandy soils are more susceptible to acidification than clayey soils. Additionally, applying too much nitrogen fertilizer can increase the risk of nitrate leaching, which can pollute groundwater. Overall, it is important to use nitrogen and zinc fertilizers in moderation and to test the soil regularly to monitor the effects of fertilization on soil chemistry as given by Moshe *et al.* (2012) and Vijendra and Ashok (2009).

4.2 Effect of different levels of nano nitrogen, sulphur and zinc on soil nutrients status after the harvest of sunflower

4.2.1 Available Nitrogen (kg ha^{-1})

Different levels of nano nitrogen, sulphur and zinc practice influence on available nitrogen (kg ha^{-1}) in soil after harvest of sunflower crop presented in Table 8. Available nitrogen in post-harvest soil differed significantly ($p < 0.05$) due to the influence of combination of different levels of nano nitrogen, sulphur and zinc and it ranged from 283.17-307.25 kg ha^{-1} . Least nitrogen content (283.17 kg ha^{-1}) in soil was recorded in control (T_1), because there was no nitrogen source applied throughout the cropping season. Among the treatments, significantly ($p < 0.05$) higher available nitrogen (307.25 kg ha^{-1}) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm+ nZn @500ppm) which recorded 303.61 kg ha^{-1} when compare to other treatment combinations.

The increases in the soil available nitrogen by application of different levels of nitrogen and zinc sulphate to the soil can be related to nitrogen fertilizer is applied to the soil, it is directly available to plants and lead to an immediate increase in the soil available nitrogen pool (Helaly *et al.*, 2014). Nitrogen fertilizer can stimulate the activity of microorganisms in the soil, which can lead to increased mineralization of organic matter. This releases nitrogen into the soil, making it

available to plants (De Rosa *et al.*, 2010). Zinc sulphate can help to reduce nitrogen losses from the soil. This is because zinc is an essential nutrient for plants and it is involved in many important plant processes, including nitrogen uptake (Shen *et al.*, 2015). When plants have enough zinc, they are able to absorb more nitrogen from the soil, which can reduce nitrogen losses. Specifically, nitrogen fertilizers can be categorized into two main types: inorganic and organic. Inorganic nitrogen fertilizers are readily available to plants, while organic nitrogen fertilizers need to be mineralized by soil microorganisms before they can be absorbed by plants as mentioned by Helaly *et al.* (2014), Jyothi and Hebsur (2017) and Kottegoda *et al.* (2011)

Zinc sulphate, on the other hand, is a micronutrient that is essential for plant growth and development. It is involved in many important plant processes, including photosynthesis, nitrogen metabolism, and auxin synthesis. When plants are deficient in zinc, they are unable to absorb nitrogen efficiently from the soil. Therefore, application of nitrogen fertilizer and zinc sulphate together can help to increase the soil available nitrogen pool in a number of ways as related by Corradini *et al.* (2010), Zhao *et al.* (2013) and Shen *et al.* (2015).

4.2.2 Available phosphorus (kg ha⁻¹)

It was observed from the data given in Table 8, that various treatments had exerted no significant ($p < 0.05$) effect on available phosphorus status of the soil after the harvest of sunflower crop. The numerically higher value of available phosphorus was observed in the treatment T₃ (29.11 kg ha⁻¹) which was applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm and was on par with treatment T₉ (29.03 kg ha⁻¹) which was applied with 25% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm when compare to treatment T₁ (absolute control) was recorded less available phosphorus (22.39 kg ha⁻¹).

4.2.3 Available potassium (kg ha⁻¹)

An appraisal of data (Table 8) showed that various treatments had exerted no significant ($p < 0.05$) difference influenced by different levels of nano nitrogen, sulphur and zinc practices on available K₂O status of soil after the sunflower harvest. Higher value is recorded for the treatment T₃ (165.02 kg ha⁻¹) which had 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm and was on par with treatment T₉ (164.29 kg ha⁻¹) which had 25% RDN + nU @ 2 ml/l

Table 8. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on available major nutrient (Nitrogen, Phosphorus and Potassium) (kg ha⁻¹) status of soil after 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

+ 25% ZnSO₄ + nS @ 200ppm + nZn @500ppm when compare to treatment T₁ (absolute control) which recorded 152.80 kg ha⁻¹ available potassium.

4.2.4 Exchangeable calcium (c mol (p⁺) kg⁻¹)

The results pertaining to exchangeable calcium (c mol (p⁺) kg⁻¹) in soil after the harvest of sunflower crop as influenced by different levels of nano nitrogen, sulphur and zinc is presented in Table 9. The data indicated that exchangeable calcium content in soil differs non-significantly between treatments and it ranges from 3.07 to 3.26 c mol (p⁺) kg⁻¹. Numerically, higher exchangeable calcium in post-harvest soil was recorded in treatment T₃ (3.26kg ha⁻¹) which had 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compared to treatment T₁ (absolute control) which recorded 3.07 c mol (p⁺) kg⁻¹

4.2.5 Exchangeable magnesium (c mol (p⁺) kg⁻¹)

The Table 9. displays the variations in exchangeable magnesium content (c mol (p⁺) kg⁻¹) in the soil after the sunflower crop harvest. This variation is a result of the application of different combinations of organic, inorganic and biofertilizers application. The results demonstrate that the levels of exchangeable magnesium in the soil did not exhibit statistically significant (p<0.05) differences across the various treatments, spanning from 1.72 - 1.83 c mol (p⁺) kg⁻¹. Specifically, the treatment T₃ which had 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm shows the highest exchangeable magnesium content at post-harvest, recorded 1.83 c mol (p⁺) kg⁻¹ compared to treatment T₁ (absolute control) which recorded 1.72 c mol (p⁺) kg⁻¹.

4.2.6 Available sulphur (mg kg⁻¹)

Different levels of nano nitrogen, sulphur and zinc practice influenced on available sulphur (mg kg⁻¹) in soil after the harvest of sunflower crop presented in Table 9. Available sulphur in post-harvest soil differed significantly (p<0.05) due to the influence of combination of different rates of nitrogen and zinc sulphate and it ranged from 6.68 to 13.28 mg kg⁻¹. Least sulphur content (6.68 mg kg⁻¹) in soil was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season. Among the treatments significantly (p<0.05) highest available sulphur (13.28 mg kg⁻¹) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₃ (12.18 mg kg⁻¹) applied with 25% RDN

Table 9. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on secondary nutrients (Exchangeable Calcium, Magnesium (c mol (p⁺) kg⁻¹) and Available Sulphur (mg kg⁻¹) status of soil after 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

+ nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm which is very close to T₄ (12.04 mg kg⁻¹) applied with 25% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compare to different treatment combinations.

The increase in soil available sulphur following the application of different levels of nitrogen and zinc sulphate to soil can be attributed to several interconnected factors. The various rates of application of zinc sulphate which contains 15 per cent sulphur is the major factor contributing for the significant ($p < 0.05$) increase over control. On the other hand, Soil microbial activity can also play a role as sulphur is mineralized from organic matter by soil microorganisms and the application of these nutrients can influence microbial populations and sulphur mineralization rates stated by Kim *et al.* (2011). Furthermore, zinc can form complexes with soil organic matter, potentially releasing sulphur bound in organic compounds. Soil redox conditions, pH and cation exchange capacity can be altered by these nutrient applications, affecting the solubility and availability of sulphur. Hence, a combination of nutrient synergies, microbial interactions and changes in soil properties collectively contribute to the increased availability of soil sulphur as noted by De Rosa *et al.* (2010), Helaly *et al.* (2014) and Shen *et al.* (2015).

4.2.7 DTPA extractable micro nutrients (mg kg⁻¹)

The availability of micronutrients (Table 10 and 11) viz., Fe, Mn, and Cu (mg kg⁻¹) in the soil after harvesting of the sunflower crop was non-significantly ($p < 0.05$) influenced except Zn, but all the organic manure applied treatments recorded the numerically higher micronutrient availability in soil than absolute control. The treatment T₃ i.e., 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm had more Fe, Mn, and Cu availability (8.20, 4.60 and 0.26 mg kg⁻¹ respectively) while the treatment T₁ i.e., absolute control had the least with 7.70, 4.35 and 0.24 mg kg⁻¹, respectively.

Whereas the availability of Zinc (mg kg⁻¹) in the soil after harvest of the crop was significantly ($p < 0.05$) influenced by different levels of nano nitrogen, sulphur and zinc (Table 9). Among the treatments significantly ($p < 0.05$) highest zinc (1.23 mg kg⁻¹) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₃ (1.00 mg kg⁻¹) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm and least zinc (0.65 mg kg⁻¹) in soil was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season.

Table 10. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on DTPA extractable micronutrient (Iron, Zinc and Manganese) (mg kg⁻¹) status of soil after the harvest of sunflower

Treatments	Details	Iron (mg kg ⁻¹)			Zinc (mg kg ⁻¹)			Manganese (mg kg ⁻¹)		
		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
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
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
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
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
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
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
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
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
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
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
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
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
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
	S.Em ±	0.22	0.23	0.23	0.02	0.03	0.02	0.12	0.12	0.12
	CD @ 5%	NS	NS	NS	0.06	0.08	0.07	NS	NS	NS

Zinc sulphate is a direct source of zinc for plants. When zinc sulphate is applied to the soil, it dissolves and releases zinc ions, which are readily available to plants (Helaly *et al.*, 2014). Nitrogen and zinc sulphate can acidify the soil, which can make zinc more available which is not desirable in terms of soil health. However, Zinc is more soluble in acidic soils than in alkaline soils. This is because the hydrogen ions in acidic soils displace the zinc ions from soil particles, making them more available to plants (Corradini *et al.*, 2010). Nitrogen and zinc sulphate can increase the activity of soil microbes, which can release zinc from organic matter. Soil microbes play an important role in the cycling of zinc in the soil. When nitrogen and zinc sulphate are applied, they can stimulate the growth and activity of soil microbes, which can lead to the release of more zinc from organic matter (Watson *et al.*, 2015). Nitrogen can increase the root biomass of plants, which can lead to increased residue addition which might contribute to the organic matter in soil that serve as a reservoir of nutrients in soil as outlined by Wenchao *et al.* (2010), Barben *et al.* (2011) and Kim *et al.* (2011)

In addition to these mechanisms, it is also possible that the increase in soil DTPA extractable zinc with the application of different levels nitrogen and zinc sulphate to soil is due to a combination of factors. It is important to note that the effect of nitrogen and zinc sulphate on soil DTPA extractable zinc will vary depending on the soil type, the amount of nitrogen and zinc sulphate applied, and the environmental conditions. (Manikadan and Subramanian (2015); Jyothi and Hebsur, (2017)).

4.2.8 Available Boron (mg kg^{-1})

The Table 11. displays the variations in available boron content (mg kg^{-1}) in the soil after the sunflower crop harvest. This variation was the result of the application different levels nano nitrogen, sulphur and zinc. The results demonstrate that the levels of available boron in the soil do not exhibit statistically significant ($p < 0.05$) differences across the various treatments, spanning from 0.28 – 0.33 mg kg^{-1} . Numerically, treatment T₁ (absolute control) recorded least boron content which is 0.28 mg kg^{-1} compare to different treatment combination which was reached up to 0.33 mg kg^{-1} .

Table 11 . Effect of different levels of Nano Nitrogen, Sulphur and Zinc on DTPA extractable Copper and available Boron (mg kg⁻¹) status of soil after the harvest of sunflower

Treatments	Details	Copper (mg kg ⁻¹)			Boron (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	0.22	0.25	0.24	0.28	0.27	0.28
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	0.23	0.26	0.25	0.32	0.33	0.32
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.25	0.27	0.26	0.32	0.34	0.33
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.24	0.27	0.25	0.32	0.33	0.33
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.24	0.26	0.25	0.32	0.33	0.33
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.23	0.26	0.25	0.32	0.33	0.32
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.23	0.26	0.24	0.32	0.33	0.32
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.23	0.26	0.24	0.32	0.33	0.32
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.24	0.27	0.26	0.32	0.34	0.33
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.24	0.27	0.26	0.32	0.33	0.33
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.24	0.26	0.25	0.32	0.33	0.33
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.23	0.26	0.25	0.32	0.33	0.32
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.23	0.26	0.24	0.32	0.33	0.32
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.23	0.26	0.24	0.31	0.33	0.32
	S.Em ±	0.01	0.01	0.01	0.01	0.01	0.01
	CD @ 5%	NS	NS	NS	NS	NS	NS

4.3 Effect of different levels of nano nitrogen, sulphur and zinc on soil biological properties after the harvest of sunflower

4.3.1 Microbial biomass carbon and nitrogen

Application of different levels nano nitrogen, sulphur and zinc influenced microbial biomass carbon and nitrogen but did not vary significantly ($p < 0.05$) among the treatments. The data (Table 12) revealed that lowest microbial biomass carbon and nitrogen (304.53 and $60.91 \mu\text{g g}^{-1}$ soil) was recorded in absolute control and numerically, the highest in treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm) (322.03 and $64.41 \mu\text{g g}^{-1}$ soil) when compared with treatments T_2 (318.56 and $63.71 \mu\text{g g}^{-1}$ soil) *i.e.*, Package of practice (FYM + Bio fertilizers + NPK + Zn + B).

4.3.2 Dehydrogenase activity

Dehydrogenase activity (DHA) is an index of microbial activity in the soil. A perusal of the data on soil dehydrogenase activity (Table 13) revealed that it varied from 71.63 to $75.53 \mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$ and the numerically highest in treatment T_9 (25% RDN + nU @ 2 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm) ($75.53 \mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$) when compared with treatments

4.3.3 Acid phosphatase activity

Perusal of the data on acid phosphatase activity (Table 13) revealed that among different treatments it did not influence significantly ($p < 0.05$). However, numerically higher acid phosphatase activity ($33.70 \mu\text{g PNP g}^{-1} \text{hr}^{-1}$) 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 ($31.93 \mu\text{g PNP g}^{-1} \text{hr}^{-1}$).

4.3.4 Urease activity

Different levels of nano nitrogen, sulphur and zinc practice had a significant influence ($p < 0.05$) on Urease activity after harvest of sunflower crop and the data is presented in Table 13.

Table 12. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on microbial biomass carbon and nitrogen ($\mu\text{g g}^{-1}$ soil) status of soil after the harvest of sunflower

Treatments	Details	Microbial biomass carbon ($\mu\text{g g}^{-1}$ soil)			Microbial biomass nitrogen ($\mu\text{g g}^{-1}$ soil)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	295.45	313.61	304.53	59.09	62.72	60.91
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	308.72	328.39	318.56	61.74	65.68	63.71
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	301.79	320.67	311.23	60.36	64.13	62.25
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	301.55	319.92	310.74	60.31	63.98	62.15
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	301.94	320.90	311.42	60.39	64.18	62.28
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	304.50	323.48	313.99	60.90	64.70	62.80
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	305.63	324.09	314.86	61.13	64.82	62.97
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	310.86	329.70	320.28	62.17	65.94	64.06
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	301.00	319.26	310.13	60.20	63.85	62.03
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	303.10	322.03	312.57	60.62	64.41	62.51
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	305.97	324.84	315.41	61.19	64.97	63.08
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	303.88	322.70	313.29	60.78	64.54	62.66
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	307.30	326.90	317.10	61.46	65.38	63.42
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	312.21	331.85	322.03	62.44	66.37	64.41
	S.Em $\pm$	8.63	9.17	8.90	1.73	1.83	1.78
	CD @ 5%	NS	NS	NS	NS	NS	NS

Among all the treatments, soil applied with treatments T₂ (22.42 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$) *i.e.*, Package of practice (FYM + Bio fertilizers + NPK + Zn + B) showed superior results over treatment T₁ (absolute control) which was closely followed with soil applied treatment T₁₄ *i.e.*, 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm treatment recorded 22.07 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$ that is on par with T₁₃, T₈, T₇, T₆ (21.47, 21.47, 21.22, 21.10 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$, respectively) and minimum nitrogen content in seed (15.01 $\mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$) was recorded in absolute control (T₁).

The application of nitrogen and zinc sulphate to soil can have influence on increasing soil microbial biomass carbon and enzyme activities, such as dehydrogenase, urease, and acid phosphate activities.

Nitrogen and zinc sulphate applications provide essential nutrients to soil microorganisms. Nitrogen is a crucial element for microbial growth, while zinc plays a role as a cofactor in various enzymatic reactions. This increased nutrient availability supports the proliferation and metabolic activities of soil microbes. Nitrogen, in the form of ammonium or nitrate, serves as a direct energy source for soil microbes as noted by Zhou *et al.* (2015), Saharan *et al.* (2012) and Kottegoda *et al.* (2011). As microorganisms assimilate these nitrogen compounds, they experience increased growth rates, leading to higher microbial biomass carbon. Adequate nitrogen and zinc levels can stimulate soil microorganisms to produce more enzymes. Dehydrogenase activity, for example, is an indicator of the overall microbial metabolic activity, while urease and acid phosphatase activities are enzymes involved in nutrient cycling processes as stated by Zhou *et al.* (2015) and Shen *et al.* (2015). Increased enzyme production facilitates more efficient nutrient turnover in the soil. Nitrogen is essential for the decomposition of organic matter, as it acts as a source of energy for decomposers. With higher nitrogen levels, organic materials break down more effectively, releasing nutrients that can be utilized by both microbes and plants. This was in line with Corradini *et al.* (2010), Moshe *et al.* (2012) and Collins *et al.* (2012).

Zinc sulphate can have an impact on soil pH. Maintaining an optimal pH range is important for soil microbial activity. Adequate zinc levels can help regulate soil pH, ensuring it remains suitable for microbial growth and enzyme activity (Manikadan and Subramanian, 2015). Nitrogen and zinc are vital for achieving balanced nutrient ratios in the soil. This can prevent nutrient imbalances that might otherwise limit microbial growth and enzymatic activity. Adequate nitrogen

Table 13. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Dehydrogenase Acid phosphatase and Urease ($\mu\text{g g}^{-1} \text{hr}^{-1}$) status of soil after the harvest of sunflower

Treatments	Details	Dehydrogenase ($\mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$)			Acid phosphatase ($\mu\text{g PNP g}^{-1} \text{hr}^{-1}$)			Urease ($\mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$)		
		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 $\pm$	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

and zinc can encourage the growth of a more diverse microbial community as noted by Saharan *et al.* (2012). This diversity enhances the functional capabilities of the soil microorganisms, leading to more efficient decomposition of organic matter and nutrient cycling. Results are in similarity with Kim *et al.* (2013), Zhao *et al.* (2013) and Helaly *et al.* (2014)

The application of nitrogen and zinc sulphate can help maintain soil health by supporting beneficial microbial populations. These microbes are essential for organic matter decomposition, nutrient mineralization, and overall soil ecosystem stability. Adequate nutrients can help soil microbes better withstand environmental stressors, such as nutrient deficiencies or imbalances, which can hinder their activities (Jyothi and Hebsur, 2017.). Enhanced microbial activity, enzyme production and nutrient cycling create a positive feedback loop that benefits the entire soil ecosystem. As more nutrients are made available through microbial processes, plant growth and soil health can improve. Proper application of nutrients, such as nitrogen and zinc sulphate, can minimize nutrient leaching and runoff, ensuring that these essential elements remain available for microbial use in the soil (Zhou *et al.* (2015), Saharan *et al.* (2012) and Barben *et al.* (2011)).

4.4 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients dynamics in soil at 30DAS, 60DAS and after the harvest of sunflower crop

4.4.1 Effect of different levels of nano nitrogen, sulphur and zinc on Nitrogen dynamics in soil

Table 14 and 15 presents data on nitrogen fractions such as nitrite, nitrate, ammonical, organic and total nitrogen at various intervals as impacted by varied levels of nano nitrogen, sulphur and zinc application approach.

4.4.1.1 Nitrite nitrogen (mg kg⁻¹)

Table 14 shows how different quantities of nano nitrogen, sulphur, and zinc practice impacted nitrite nitrogen (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. This nitrite nitrogen fraction in soil differed significantly ($p < 0.05$) due to the influence of combination of different rates of nitrogen and zinc sulphate. Among the treatments significantly ($p < 0.05$) highest nitrite nitrogen (7.33, 6.81 and 6.56 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio

fertilizers + NPK + Zn + B)) and followed by treatment T₁₃ (6.52, 6.08 and 5.87 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm when compare to different treatment combinations. Least nitrite nitrogen content (4.33, 4.08 and 3.96 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁).

4.4.1.2 Nitrate nitrogen (mg kg⁻¹)

Table 14 illustrates how varied amounts of nano nitrogen, sulphur, and zinc practice affected the amount of nitrate nitrogen (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. The impact of varied nitrogen and zinc sulphate rates on the nitrate nitrogen fraction in soil was significant ($p < 0.05$). Least nitrate nitrogen content (31.02, 29.26 and 28.41 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁). Among the treatments significantly ($p < 0.05$) highest nitrate nitrogen (52.50, 48.79 and 47.00 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₁₃ (46.76, 43.57 and 42.03 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm when compare to different treatment combinations.

4.4.1.3 Ammonical nitrogen (mg kg⁻¹)

Different levels of nano nitrogen, sulphur and zinc practice influenced on ammonical nitrogen (mg kg⁻¹) in soil at 30DAS, 60DAS and after the harvest of sunflower crop presented in Table 14. This ammonical nitrogen fraction in soil differed significantly ($p < 0.05$) due to the influence of combination of different rates of nitrogen and zinc sulphate. Least ammonical nitrogen content (138.71, 127.25 and 120.96 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season. Among the treatments significantly ($p < 0.05$) highest ammonical nitrogen (150.46, 138.04 and 131.21 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₁₄ (147.71, 135.51 and 128.81 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm which is very close to T₁₃ (147.44, 135.26 and

128.58 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm when compare to different treatment combinations.

4.4.1.4 Organic nitrogen (mg kg⁻¹)

Table 15 shows the effect of different quantities of nano nitrogen, sulphur, and zinc on organic nitrogen (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. As a result of the impact of differing rates of nitrogen and zinc sulphate, the organic nitrogen fraction in soil did not change significantly ($p < 0.05$). Among the treatments numerically ($p < 0.05$) highest Organic nitrogen (903.07, 876.85 and 867.05 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) when compare to absolute control (T₁) recorded least organic nitrogen content (880.11, 857.58 and 845.01 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, because there were neither FYM nor fertilizer sources applied throughout the cropping season.

4.4.1.5 Total nitrogen (mg kg⁻¹)

Table 15 shows how different amounts of nano nitrogen, sulphur, and zinc practice impact total nitrogen (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. In view of the impact of differing rates of nitrogen and zinc sulphate, the total nitrogen in soil did not change significantly ($p < 0.05$). when compare to absolute control (T₁) recorded Least total nitrogen content (1074.04, 1033.46 and 1017.38 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, highest total nitrogen (1134.12 1089.59 and 1071.67 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) was noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)).

The application of nitrogen, plays a significant role in augmenting nitrogen availability within the soil. Nitrogen, especially in the form of ammonium found in nitrogen fertilizers, undergoes a transformation within the soil, converting into diverse nitrogen fractions including nitrite, nitrate, and organic nitrogen, facilitated by both microbial and chemical processes (Qin *et al.*, 2017). The microbial activity within the soil predominantly mediates these nitrogen transformations. Elevated nitrogen levels introduced through application can stimulate microbial populations, resulting in heightened activity in nitrification and ammonification processes. These

Table 14. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on nitrogen fractions at 30DAS, 60DAS and after the harvest of sunflower

Nitrogen Fractions (ppm) at different intervals (Pooled Data of two seasons)										
Treatments	Details	Nitrite N			Nitrate N			Ammonical N		
		30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest
T ₁	Absolute control	4.33	4.08	3.96	31.02	29.26	28.41	138.71	127.25	120.96
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	7.33	6.81	6.56	52.50	48.79	47.00	150.46	138.04	131.21
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.60	5.30	5.15	40.16	37.96	36.90	141.06	129.41	123.02
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.50	5.21	5.06	39.45	37.31	36.28	141.24	129.58	123.17
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.92	5.58	5.42	42.40	39.99	38.83	142.93	131.13	124.65
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.86	5.53	5.37	41.99	39.63	38.49	143.38	131.54	125.04
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	6.37	5.94	5.73	45.64	42.55	41.07	145.44	133.43	126.84
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	6.30	5.88	5.67	45.17	42.13	40.66	146.10	134.04	127.42
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	5.80	5.48	5.32	41.59	39.26	38.14	142.12	130.38	123.94
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	5.74	5.42	5.27	41.12	38.84	37.73	141.80	130.10	123.67
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.24	5.82	5.62	44.74	41.73	40.29	143.53	131.68	125.17
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.21	5.79	5.59	44.49	41.51	40.07	144.32	132.41	125.86
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.52	6.08	5.87	46.76	43.57	42.03	147.44	135.26	128.58
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.47	6.03	5.82	46.38	43.23	41.71	147.71	135.51	128.81
	S.Em ±	0.17	0.16	0.15	1.20	1.12	1.09	4.08	3.74	3.56
	CD @ 5%	0.48	0.46	0.44	3.48	3.26	3.16	11.85	10.87	10.33

Table 15. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on nitrogen fractions at 30DAS, 60DAS and after the harvest of sunflower

Nitrogen Fractions (ppm) at different intervals (Pooled Data of two seasons)							
Treatments	Details	Organic N			Total N		
		30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest
T ₁	Absolute control	884.11	857.58	849.01	1074.04	1033.46	1017.38
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	903.07	876.85	867.05	1134.12	1089.59	1071.67
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	888.71	862.04	853.42	1091.67	1050.24	1033.77
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	889.06	862.38	853.76	1091.38	1050.00	1033.56
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	892.36	865.58	856.93	1099.86	1057.93	1041.22
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	893.24	866.44	857.77	1100.74	1058.79	1042.07
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	897.27	870.35	861.64	1111.14	1068.06	1050.81
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	898.56	871.60	862.88	1112.58	1069.45	1052.19
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	890.77	864.04	855.40	1096.48	1054.76	1038.14
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	890.16	863.45	854.82	1095.01	1053.37	1036.81
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	893.53	866.72	858.05	1104.36	1061.65	1044.57
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	895.08	868.22	859.54	1106.45	1063.65	1046.53
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	901.16	874.12	865.38	1118.41	1074.92	1057.49
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	901.69	874.63	865.89	1118.79	1075.30	1057.87
	S.Em ±	25.42	24.66	24.41	31.31	30.12	29.64
	CD @ 5%	NS	NS	NS	NS	NS	NS

processes facilitate the conversion of ammonium into different nitrogen forms such as nitrite, nitrate, and various organic nitrogen compounds as noted by Zhou *et al.* (2015), Zang *et al.* (2015) and Liu *et al.* (2013)

The application of nitrogen influences the decomposition of organic matter within the soil. Microbial activity triggers the breakdown of organic materials, leading to the release of various forms of organic nitrogen. Additionally, the application of zinc sulphate has the potential to interact with other soil nutrients, possibly affecting the soil environment, which can consequently influence the transformation and availability of nitrogen in diverse forms (Zakia *et al.*, (2007). Changes in soil pH due to zinc sulphate application may impact nitrogen transformations, thereby affecting the distribution of different nitrogen fractions in the soil. Furthermore, the application of nitrogen and zinc sulphate can affect the release of substances from plant roots and their uptake, subsequently influencing the availability and distribution of nitrogen forms within the soil (Li *et al.*, 2014). Variations in soil moisture, temperature and aeration levels, influenced by nutrient applications, can modify microbial activity, subsequently impacting nitrogen fractions in the soil. Alterations in nutrient applications can also impact soil sorption and desorption processes, affecting the availability and transformation of various nitrogen fractions. Changes in soil redox conditions due to nutrient applications may influence the conversion of nitrogen forms, particularly between different oxidation states. These results are in con current with Liu *et al.* (2022), Zhou *et al.* (2015), Li *et al.* (2014) and Zakia *et al.* (2007).

4.4.2 Effect of different levels of nano nitrogen, sulphur and zinc on Sulphur dynamics in soil

The data pertaining to Sulphur fractions like water soluble, exchangeable, inorganic, residual, organic and total sulphur at different intervals as influenced by different level of nano nitrogen, sulphur and zinc application practice presented in Table 16 and 17.

4.4.2.1 Water soluble sulphur (mg kg^{-1})

Different levels of nano nitrogen, sulphur and zinc practice influenced on water soluble sulphur (mg kg^{-1}) in soil at 30DAS, 60DAS and after the harvest of sunflower crop presented in Table 16. This water-soluble sulphur fractions in soil differed significantly ($p < 0.05$) due to the influence of combination of different rates of nitrogen and zinc sulphate. Least water-soluble sulphur content ($4.79, 4.43$ and 4.19 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower,

respectively) in soil was recorded in absolute control (T_1), because there were no fertilizer sources applied throughout the cropping season. Among the treatments significantly ($p < 0.05$) highest water soluble sulphur (8.63, 7.95 and 7.50 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T_3 (8.05, 7.42 and 7.00 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm which is very close to T_4 (7.96, 7.34 and 6.93 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compare to different treatment combinations.

4.4.2.2 Extractable sulphur (mg kg⁻¹)

Table 16 shows how different quantities of nano nitrogen, sulphur, and zinc practice impacted extractable sulphur (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. This extractable sulphur fractions in soil differed significantly ($p < 0.05$) due to the influence of combination of different rates of nitrogen and zinc sulphate. Among the treatments significantly ($p < 0.05$) highest Extractable sulphur (6.56, 5.91 and 5.52 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T_3 (5.89, 5.29 and 4.93 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm then by T_4 (5.81, 5.22 and 4.87 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compare to different treatment combinations. Least extractable sulphur content (2.85, 2.54 and 2.36 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T_1), because there were no fertilizer sources applied throughout the cropping season

4.4.2.3 Inorganic sulphur (mg kg⁻¹)

Table 16 illustrates how varied amounts of nano nitrogen, sulphur, and zinc practice affected the amount of Inorganic sulphur (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. The impact of varied nitrogen and zinc sulphate rates on the Inorganic sulphur fractions in soil was significant ($p < 0.05$). Least Inorganic sulphur content (32.52, 31.25 and 30.23 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in

absolute control (T_1). Among the treatments significantly ($p < 0.05$) highest Inorganic sulphur (38.23, 36.32 and 35.23 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T_3 (37.85, 35.96 and 34.88 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO_4 + nS @ 100ppm + nZn @ 250ppm when compare to different treatment combinations.

4.4.2.4 Residual sulphur (mg kg^{-1})

Different levels of nano nitrogen, sulphur and zinc practice influence on Residual sulphur (mg kg^{-1}) in soil at 30DAS, 60DAS and after the harvest of sunflower crop presented in Table 17. The impact of varied rates of nitrogen and zinc sulphate on residual sulphur fractions in soil did not differ significantly ($p < 0.05$). Among the treatments numerically ($p < 0.05$) highest Residual sulphur (66.78, 63.87 and 62.11 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) when compare to absolute control (T_1) recorded residual sulphur content (59.84, 57.43 and 55.88 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, because there were no fertilizer sources applied throughout the cropping season.

4.4.2.5 Organic sulphur (mg kg^{-1})

Table 17 shows the effect of different quantities of nano nitrogen, sulphur, and zinc on organic sulphur (mg kg^{-1}) in soil at 30DAS, 60DAS, and after sunflower crop harvest. As a result of the impact of differing rates of nitrogen and zinc sulphate, the organic sulphur fractions in soil did not change significantly ($p < 0.05$). Among the treatments numerically ($p < 0.05$) highest Organic sulphur (265.28, 259.97 and 257.37 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) when compare to absolute control (T_1) recorded least organic sulphur content (256.23, 249.23 and 243.25 mg kg^{-1} at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, because there were neither FYM nor fertilizer sources applied throughout the cropping season.

4.4.2.6 Total sulphur (mg kg⁻¹)

Table 17 shows how different amounts of nano nitrogen, sulphur, and zinc practice impact total sulphur (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. In view of the impact of differing rates of nitrogen and zinc sulphate, the total sulphur percentages in soil did not change significantly ($p < 0.05$). when compare to absolute control (T₁) recorded Least total sulphur content (258.70, 347.67 and 339.74 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, highest total sulphur (391.47, 379.35 and 372.79 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) was noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)).

Zinc sulphate, while primarily a zinc source, contains sulphur as well. Additionally, the application of nitrogen may indirectly affect soil sulphur fractions. Increased availability of these nutrients in the soil can contribute to higher levels of available sulphur forms. Sulphur can be present in various forms in soil, including water-soluble, extractable, inorganic, residual, and organic fractions (Zhou *et al.* (2014) and Collins *et al.* (2012)). The application of zinc sulphate and nitrogen may assist in mobilizing sulphur from less available forms (such as residual or organic sulphur) to more soluble and extractable forms. Sulphur, especially in organic forms, needs to be mineralized to become available for plant and microbial uptake. Nitrogen can stimulate microbial activity, leading to increased mineralization of organic sulphur into forms that are more accessible for plants and soil processes as outlined by Liu *et al.* (2022), Zhou *et al.* (2014), Zhou *et al.* (2018) and Wanyika (2012).

The application of zinc sulphate can influence soil pH, potentially affecting sulphur forms. Changes in pH levels can impact the solubility and availability of various sulphur fractions in the soil. Sulphur transformations in soil are often mediated by microbial activity. Nitrogen application can stimulate microbial populations, leading to increased biological activity involved in sulphur cycling, which may influence the different sulphur fractions in the soil. Zinc interacts with other nutrients and can affect soil chemistry. This interaction might indirectly impact the availability and transformation of sulphur fractions in the soil (Liu *et al.* (2022), Chen *et al.* (2018) and Zhou *et al.* (2016)). Nitrogen can stimulate decomposition of organic matter, releasing sulphur previously bound in organic forms. This breakdown leads to an increase in available sulphur fractions. Plants exude various compounds into the rhizosphere, affecting the soil's chemical environment.

Table 16. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on sulphur fractions at 30DAS, 60DAS and after the harvest of sunflower

Sulphur Fractions (mg kg ⁻¹) at different intervals (Pooled Data of two seasons)										
Treatments	Details	Water soluble S			Extractable S			Inorganic S		
		30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest
T ₁	Absolute control	4.79	4.43	4.19	2.85	2.54	2.36	32.52	31.25	30.23
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	8.63	7.95	7.50	6.56	5.91	5.52	38.23	36.32	35.23
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	8.05	7.42	7.00	5.89	5.29	4.93	37.85	35.96	34.88
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.96	7.34	6.93	5.81	5.22	4.87	35.04	33.29	32.29
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.80	7.19	6.79	5.65	5.08	4.74	34.92	33.17	32.18
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.70	7.11	6.71	5.56	5.00	4.66	34.72	32.98	31.99
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.60	7.01	6.62	5.47	4.92	4.58	34.45	32.73	31.75
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.57	6.98	6.59	5.44	4.88	4.55	34.26	32.55	31.57
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	6.14	5.67	5.36	4.10	3.67	3.41	34.02	32.32	31.35
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.24	5.76	5.44	4.18	3.75	3.49	34.12	32.41	31.44
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.06	5.60	5.29	4.02	3.60	3.35	33.89	32.20	31.23
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	5.75	5.31	5.02	3.74	3.34	3.11	33.42	31.75	30.80
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	5.96	5.50	5.20	3.93	3.52	3.27	33.68	32.00	31.04
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	5.60	5.17	4.89	3.60	3.22	2.99	33.15	31.49	30.55
	S.Em ±	0.19	0.18	0.17	0.13	0.12	0.11	0.98	0.93	0.90
	CD @ 5%	0.55	0.51	0.48	0.38	0.34	0.32	2.84	2.71	2.62

Table 17. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on sulphur fractions at 30DAS, 60DAS and after the harvest of sunflower

[illegible]

Increased availability of nitrogen and zinc sulphate might alter root exudation, influencing the transformation and availability of sulphur fractions (Chen *et al.* (2018), Helaly *et al.* (2014) and Zhou *et al.* (2017). Changes in nutrient applications can influence the sorption and desorption processes in soil, impacting the availability of different sulphur forms. Alterations in redox conditions in the soil due to nutrient applications can affect the transformation of sulphur forms, especially between inorganic and organic fractions. Similar results were outlined by Moshe *et al.* (2012), Zhou *et al.* (2018), Collins *et al.* (2012) and Kim *et al.* (2013).

4.4.3 Effect of different levels of nano nitrogen, sulphur and zinc on Zinc dynamics in soil

The data pertaining to zinc fractions like water soluble and exchangeable, organic matter bound, acid soluble and total zinc at different intervals as influenced by different level of nano nitrogen, sulphur and zinc application practice presented in Table 18 and 19.

4.4.3.1 Water soluble and exchangeable zinc (mg kg⁻¹)

Table 18 illustrates how varied amounts of nano nitrogen, sulphur, and zinc practice affected the amount of water soluble and exchangeable zinc (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. The impact of varied nitrogen and zinc sulphate rates on the water soluble and exchangeable zinc fractions in soil was significant ($p < 0.05$). Least Water soluble and exchangeable zinc content (0.54, 0.48 and 0.44 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁). Among the treatments significantly ($p < 0.05$) highest water soluble and exchangeable zinc (1.39, 1.28 and 1.21 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₃ (1.13, 1.04 and 0.98 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm when compare to different treatment combinations.

4.4.3.2 Organic matter bound zinc (mg kg⁻¹)

Different levels of nano nitrogen, sulphur and zinc practice influenced on organic matter bound zinc (mg kg⁻¹) in soil at 30DAS, 60DAS and after the harvest of sunflower crop presented in Table 18. This organic matter bound zinc fraction in soil differed significantly ($p < 0.05$) due to

the influence of combination of different rates of nitrogen and zinc sulphate. Least organic matter bound zinc content (0.73, 0.68 and 0.65 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season. Among the treatments significantly (p<0.05) highest organic matter bound zinc (2.53, 2.34 and 2.25 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) and followed by treatment T₃ (2.12, 1.97 and 1.89 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 2 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm which is very close to T₄ (2.07, 1.91 and 1.84 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) applied with 25% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compare to different treatment combinations.

4.4.3.3 Acid soluble zinc (mg kg⁻¹)

Table 19 shows how different quantities of nano nitrogen, sulphur, and zinc practice impacted acid soluble zinc (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. This acid soluble zinc fraction in soil did not differed significantly (p<0.05) due to the influence of combination of different rates of nitrogen and zinc sulphate. Among the treatments numerically, highest acid soluble zinc (17.42, 16.37 and 15.87 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)). when compare to different treatment combinations. Least acid soluble zinc content (11.67, 10.96 and 10.61 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season

4.4.3.4 Residual zinc (mg kg⁻¹)

Different levels of nano nitrogen, sulphur and zinc practice influence on Residual zinc (mg kg⁻¹) in soil at 30DAS, 60DAS and after the harvest of sunflower crop presented in Table 19. The impact of varied rates of nitrogen and zinc sulphate on residual zinc fractions in soil did not differ significantly (p<0.05). Among the treatments numerically (p<0.05) highest Residual zinc (134.96, 125.56 and 121.04 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) noticed in treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) when

compare to absolute control (T_1) recorded residual zinc content (109.20, 101.01 and 97.03 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, because there were no fertilizer sources applied throughout the cropping season.

4.4.3.5 Total zinc (mg kg⁻¹)

Table 19 shows how different amounts of nano nitrogen, sulphur, and zinc practice impact total zinc (mg kg⁻¹) in soil at 30DAS, 60DAS, and after sunflower crop harvest. In view of the impact of differing rates of nitrogen and zinc sulphate, the total zinc did not change significantly ($p < 0.05$). when compare to absolute control (T_1) recorded Least total zinc content (120.13, 111.91 and 107.94 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) in soil, highest total zinc (167.77, 154.57 and 148.21 mg kg⁻¹ at 30DAS, 60DAS and after the harvest of sunflower, respectively) was noticed in treatment T_2 (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)).

Direct application of zinc sulphate increases the presence of soluble zinc in the soil, contributing to elevated levels of water-soluble zinc fractions. Zinc sulphate application interacts with the soil matrix and other nutrients. This interaction might increase the exchangeable fraction of zinc, making it more readily available for plant uptake. Increased nitrogen levels might influence organic matter breakdown, potentially releasing zinc from organic matter into the soil solution, impacting the organic matter-bound fraction of zinc (Zhou *et al.* (2017) and Zhou *et al.* (2013)). Zinc sulphate application, potentially altering soil pH, can influence the solubility of zinc. Changes in pH levels can lead to an increase in the acid-soluble fraction of zinc. The application of zinc sulphate, along with changes induced by nitrogen levels, may influence the transformation of residual zinc, the fraction that remains in the soil even after exhaustive extractions as depicted by Zhou *et al.* (2016), Zhou *et al.* (2012), De Rosa *et al.* (2010) and Wenchao *et al.* (2010).

The collective effect of nitrogen and zinc sulphate applications can contribute to an overall increase in the total zinc content in the soil, reflecting the sum of all fractions of zinc present. Zinc sulphate application, in conjunction with nitrogen, can potentially affect root exudation and plant uptake, influencing the distribution and availability of zinc fractions in the soil as stated by Zhou *et al.* (2014) and Chen *et al.* (2018). Changes induced by nitrogen levels and zinc sulphate can affect soil microbial populations, potentially impacting the transformation and distribution of zinc fractions in the soil. Alterations in nutrient applications can affect the sorption and desorption

Table 18. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on zinc fractions at 30DAS, 60DAS and after the harvest of sunflower

Zinc Fractions (ppm) at different intervals (Pooled Data of two seasons)							
Treatments	Details	Water soluble and exchangeable Zn			Organic matter bound Zn		
		30DAS	60 DAS	At harvest	30DAS	60 DAS	At harvest
T ₁	Absolute control	0.54	0.48	0.44	0.73	0.68	0.65
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	1.39	1.28	1.21	2.53	2.34	2.25
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.13	1.04	0.98	2.12	1.97	1.89
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.12	1.03	0.97	2.07	1.91	1.84
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.09	1.00	0.94	2.00	1.85	1.78
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.11	1.02	0.96	2.02	1.87	1.80
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.04	0.96	0.90	1.97	1.82	1.75
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.03	0.95	0.89	1.91	1.77	1.70
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.88	0.81	0.76	1.55	1.44	1.38
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.85	0.78	0.74	1.51	1.39	1.34
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.83	0.76	0.72	1.47	1.36	1.31
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.78	0.72	0.68	1.40	1.30	1.25
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.79	0.73	0.69	1.44	1.33	1.28
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.77	0.71	0.67	1.38	1.28	1.23
	S.Em ±	0.03	0.02	0.02	0.05	0.04	0.04
	CD @ 5%	0.07	0.07	0.07	0.14	0.13	0.12

processes in the soil, impacting the availability and transformation of zinc fractions. Changes in soil moisture, temperature, and aeration levels influenced by nutrient applications can modify the distribution of zinc fractions within the soil. Results are in line with Liu *et al.* (2022), Kottegoda *et al.* (2011), Zhou *et al.* (2013), Zhou *et al.* (2014) and Kim *et al.* (2013).

4.5 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients concentration in sunflower seeds and stalk

4.5.1 Nitrogen (%) concentration in sunflower seeds and stalk.

The data pertaining to nitrogen (%) content in sunflower seeds and stalk as influenced by different level of nano nitrogen, sulphur and zinc application practice presented in Table 20 and 21.

Among all the treatments combinations, treatment T₁₄ *i.e.*, 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm showed superior results over treatment T₁ (absolute control) and it ranged from 3.03 to 3.69 per cent in seeds and 0.71 to 0.90 per cent in stalk. The maximum nitrogen content in seed (3.69%) and stalk (0.90%) was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) and was on par with treatment T₆ (3.65 and 0.89% in seed and stalk, respectively) which had 50% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm when compared with treatments T₂ (3.26 and 0.74% in seed and stalk, respectively) *i.e.*, Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and minimum nitrogen content in seed (3.03%) and stalk (0.71%) was recorded in absolute control (T₁).

The elevation of nitrogen concentration in sunflower seeds and stalk through the application of various levels of nano nitrogen as a foliar spray can be ascribed to several pivotal factors. Nano nitrogen, being in a highly soluble and plant-accessible form, facilitates efficient absorption through the leaves, thereby ushering in an increased influx of nitrogen into the plant (Badran and Savin, 2017). This increased absorption comes up not only from the accuracy of foliar application, but also from the decrease of nitrogen losses, as traditional soil-applied fertilizers frequently suffer from leaching or gaseous volatilization as indicated by Chandana *et al.* (2021)

Nano nitrogen as a foliar spray offers a targeted and efficient mode of nutrient delivery, resulting in higher nitrogen concentrations in the seeds and stalk. Moreover, the nano-sized

particles exhibit improved mobility within the plant, enabling rapid translocation of nitrogen to various plant components outlined by Hafeez *et al.* (2015). Additionally, the use of nano-based foliar sprays aligns with environmentally responsible agricultural practices, curbing nitrogen's impact on the environment. Finally, the flexibility to fine-tune nutrient application with different levels of nano nitrogen ensures optimized nutrient management, while mitigating nitrogen stress, thereby enhancing the nitrogen content in the harvested crop (Azamal and Khawaja, 2014). In addition, nano nitrogen foliar sprays present a promising approach to augment nitrogen concentrations in sunflower seeds and stalk, fostering both sustainable agricultural practices and enhanced crop productivity. These results as stated by Abasalt *et al.* (2015), WA Al-juthery *et al.* (2019), Fan *et al.* (2012) and Ma *et al.* (2010).

4.5.2 Phosphorus (%) concentration in sunflower seeds and stalk.

Different levels of nano nitrogen, sulphur and zinc practice did not influence significantly ($p < 0.05$) on phosphorus percentage in seed and stalk after harvest of sunflower crop and the data is presented in Table 20 and 21.

Phosphorus percentage in post-harvest seed and stalk didn't differ significantly ($p < 0.05$) and it ranged from 0.90 to 0.92 per cent in seeds and 0.25 to 0.28 per cent in stalk. The maximum phosphorus content in seed (0.92%) and stalk (0.28%) was recorded in treatment T₁₃ (75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) when compared with treatments T₂ (0.90 and 0.25% in seed and stalk, respectively) i.e., Package of practice (FYM + Bio fertilizers + NPK + Zn + B).

4.5.3 Potassium (%) concentration in sunflower seeds and stalk.

The data pertaining to potassium (%) content in sunflower seeds and stalk as influenced by different levels of nano nitrogen, sulphur and zinc practice and presented in Table 20 and 21.

Among all the treatments, potassium percentage in post-harvest seed and stalk didn't differed significantly ($p < 0.05$) and it ranged from 1.04 to 1.07 per cent in seeds and 1.35 to 1.37 per cent in stalk. The maximum potassium content in seed (1.07%) and stalk (1.37%) was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) when

Table 20. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of major nutrients (N, P and K) (%) in sunflower seeds after the harvest

Treatments	Details	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	3.05	3.02	3.03	0.9	0.90	0.90	1.04	1.03	1.04
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	3.27	3.25	3.26	0.9	0.89	0.90	1.05	1.04	1.05
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.38	3.35	3.36	0.91	0.90	0.91	1.05	1.04	1.05
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.57	3.55	3.56	0.91	0.91	0.91	1.06	1.05	1.06
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.47	3.44	3.45	0.9	0.89	0.90	1.05	1.04	1.05
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.67	3.63	3.65	0.91	0.88	0.90	1.06	1.04	1.05
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.49	3.47	3.48	0.92	0.89	0.91	1.05	1.04	1.05
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.65	3.61	3.63	0.91	0.90	0.91	1.05	1.02	1.04
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	3.41	3.38	3.39	0.92	0.90	0.91	1.06	1.05	1.06
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.55	3.50	3.53	0.91	0.89	0.90	1.07	1.04	1.06
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.45	3.42	3.43	0.91	0.90	0.91	1.07	1.06	1.07
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.61	3.58	3.60	0.92	0.90	0.91	1.06	1.07	1.07
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.51	3.47	3.49	0.93	0.91	0.92	1.06	1.06	1.06
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.7	3.67	3.69	0.93	0.89	0.91	1.07	1.07	1.07
	S.Em ±	0.10	0.09	0.09	0.03	0.03	0.03	0.04	0.04	0.04
	CD @ 5%	0.29	0.27	0.28	NS	NS	NS	NS	NS	NS

Table 21. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of major nutrients (N, P and K) (%) in sunflower stalk after the harvest

Treatments	Details	Nitrogen (%)			Phosphorus (%)			Potassium (%)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	0.70	0.71	0.71	0.25	0.24	0.25	1.35	1.34	1.35
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	0.75	0.72	0.74	0.25	0.24	0.25	1.35	1.35	1.35
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.79	0.78	0.79	0.26	0.23	0.25	1.35	1.35	1.35
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.8	0.79	0.80	0.25	0.24	0.25	1.35	1.34	1.35
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.83	0.85	0.84	0.26	0.24	0.25	1.36	1.35	1.36
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.89	0.88	0.89	0.26	0.25	0.26	1.35	1.34	1.35
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.81	0.78	0.80	0.26	0.24	0.25	1.35	1.34	1.35
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.87	0.88	0.88	0.26	0.25	0.26	1.35	1.35	1.35
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.79	0.80	0.80	0.27	0.27	0.27	1.34	1.35	1.35
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.85	0.84	0.85	0.25	0.27	0.26	1.35	1.35	1.35
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.81	0.79	0.80	0.27	0.26	0.27	1.35	1.36	1.36
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.88	0.87	0.88	0.26	0.26	0.26	1.36	1.35	1.36
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.81	0.81	0.81	0.27	0.28	0.28	1.36	1.36	1.36
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.9	0.89	0.90	0.27	0.27	0.27	1.37	1.36	1.37
	S.Em ±	0.02	0.02	0.02	0.01	0.01	0.01	0.04	0.04	0.04
	CD @ 5%	0.07	0.07	0.07	NS	NS	NS	NS	NS	NS

compared with treatments T₂ (1.05 and 1.35% in seed and stalk, respectively) *i.e.*, Package of practice (FYM + Bio fertilizers + NPK + Zn + B)

4.5.4 Calcium (%) concentration in sunflower seeds and stalk

The calcium concentration in sunflower seeds and stalk as influenced by different levels of nano nitrogen, sulphur and zinc practice presented in Table 22 and 23 and it was non-significant ($p < 0.05$).

Calcium percentage in post-harvest seed and stalk didn't differed significantly ($p < 0.05$) and it ranged from 0.10 to 0.12 per cent in seeds and 0.53 to 0.57 per cent in stalk. The maximum calcium content in seed (0.12%) and stalk (0.57%) was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) when compared with treatments T₁ (0.10 and 0.53% in seed and stalk, respectively) *i.e.*, absolute control.

4.5.5 Magnesium (%) concentration in sunflower seeds and stalk.

Different levels of nano nitrogen, sulphur and zinc practice influence on magnesium percentage in seed and stalk after harvest of sunflower crop presented in Table 22 and 23.

Magnesium percentage in post-harvest seed and stalk didn't differed significantly ($p < 0.05$) and it ranged from 0.18 to 0.19 per cent in seeds and 0.29 to 0.32 per cent in stalk. The maximum magnesium content in seed (0.19%) and stalk (0.32%) was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) and similar was found in other treatments as well when compared with treatments T₁ (0.18 and 0.32% in seed and stalk, respectively) *i.e.*, absolute control.

4.5.6 Sulphur (%) concentration in sunflower seeds and stalk.

The results on sulphur (%) content in sunflower seeds and stalk as influenced by different combinations of nano nitrogen, sulphur and zinc practice was significant ($p < 0.05$) among the treatments and presented in Table 22 and 23.

Among all the treatments, soil applied with 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm treatment showed superior results over treatment T₁ (absolute control) and it ranged from 0.39 to 0.53 per cent in seeds and 0.13 to 0.23 per cent in stalk. The maximum

Table 22. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of secondary nutrients (Ca, Mg and S) (%) in sunflower seeds and stalk after the harvest

Treatments	Details	Calcium (%)			Magnesium (%)			Sulphur (%)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	0.1	0.09	0.10	0.18	0.17	0.18	0.41	0.37	0.39
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	0.1	0.09	0.10	0.19	0.19	0.19	0.44	0.42	0.43
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.11	0.11	0.11	0.18	0.18	0.18	0.46	0.42	0.44
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.11	0.1	0.11	0.18	0.19	0.19	0.47	0.46	0.47
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.11	0.1	0.11	0.18	0.17	0.18	0.47	0.45	0.46
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.1	0.1	0.10	0.18	0.17	0.18	0.49	0.46	0.47
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.11	0.09	0.10	0.18	0.17	0.18	0.48	0.46	0.47
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.11	0.11	0.11	0.18	0.19	0.19	0.49	0.45	0.47
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.12	0.1	0.11	0.19	0.18	0.19	0.52	0.50	0.51
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.11	0.09	0.10	0.19	0.17	0.18	0.51	0.48	0.49
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.11	0.1	0.11	0.20	0.18	0.19	0.52	0.49	0.50
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.12	0.11	0.12	0.19	0.17	0.18	0.53	0.51	0.52
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.12	0.11	0.12	0.19	0.19	0.19	0.50	0.52	0.51
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.12	0.11	0.12	0.20	0.18	0.19	0.53	0.53	0.53
	S.Em ±	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01
	CD @ 5%	NS	NS	NS	NS	NS	NS	0.04	0.04	0.04

Table 23. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of secondary nutrients (Ca, Mg and S) (%) in sunflower stalk after the harvest

Treatments	Details	Calcium (%)			Magnesium (%)			Sulphur (%)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	0.56	0.5	0.53	0.29	0.29	0.29	0.13	0.12	0.13
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	0.6	0.54	0.57	0.30	0.30	0.30	0.16	0.14	0.15
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.59	0.53	0.56	0.30	0.29	0.30	0.17	0.16	0.17
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.59	0.53	0.56	0.30	0.31	0.31	0.17	0.16	0.17
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.6	0.54	0.57	0.31	0.29	0.30	0.18	0.18	0.18
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.6	0.54	0.57	0.31	0.30	0.31	0.17	0.18	0.18
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.6	0.54	0.57	0.31	0.30	0.31	0.18	0.18	0.18
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	0.6	0.54	0.57	0.31	0.29	0.30	0.18	0.17	0.18
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	0.59	0.53	0.56	0.31	0.28	0.30	0.2	0.2	0.20
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.59	0.53	0.56	0.31	0.28	0.30	0.2	0.21	0.21
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.6	0.54	0.57	0.32	0.31	0.32	0.21	0.21	0.21
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.6	0.54	0.57	0.32	0.31	0.32	0.22	0.22	0.22
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.6	0.54	0.57	0.32	0.30	0.31	0.2	0.21	0.21
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	0.6	0.54	0.57	0.32	0.31	0.32	0.22	0.23	0.23
	S.Em ±	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01
	CD @ 5%	NS	NS	NS	NS	NS	NS	0.02	0.02	0.02

sulphur content in seed (0.53%) and stalk (0.23%) was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) and was on par with treatment T₁₂ (0.52% in seed and 0.22% in stalk) which had 50% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm and differed significantly ($p<0.05$) with treatments T₂ (0.43% in seed and 0.15% in stalk) *i.e.*, Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and minimum nitrogen content in seed (0.39% in seed and 0.13% stalk) was recorded in absolute control (T₁).

The rise in sulphur concentration within sunflower seeds and stalk, stemming from the application of varying levels of nano sulphur as a foliar spray, can be attributed to a range of pivotal factors (Sarkar *et al.*, 2013). Nano sulphur, in its highly soluble and readily plant-accessible form, offers an efficient avenue for sulphur uptake through the leaves, leading to an elevated influx of sulphur within the plant and consequently higher sulphur concentrations in both the seeds and stalk as stated by Azamal and Khawaja (2014). Moreover, this approach significantly ($p<0.05$) reduces sulphur losses, as it mitigates the risk of leaching and atmospheric volatilization commonly associated with traditional soil-applied sulphur fertilizers. Nano sulphur foliar sprays enable precise and targeted nutrient delivery, ensuring minimal wastage and direct absorption by the plant, thereby contributing to a more effective sulphur supply as outlined by Patel *et al.* (2019).

Additionally, the nano-sized sulphur particles exhibit enhanced mobility within the plant, facilitating the translocation of sulphur to various plant parts, including the seeds and stalk. This method fosters a rapid uptake of sulphur and results in quicker accumulation (Sarkar *et al.*, 2013; Mandal *et al.*, 2015). Furthermore, it aligns with environmentally conscious agricultural practices by minimizing excess sulphur in the soil, reducing environmental concerns such as soil acidification. Hafeez *et al.* (2015) mentioned that the flexibility to fine-tune sulphur application with different levels of nano sulphur ensures optimized nutrient management, while also alleviating sulphur-induced stress on the plants, thus enhancing sulphur concentrations in the harvested crop. Overall, nano sulphur foliar sprays present a promising strategy for elevating sulphur content in sunflower seeds and stalk, promoting sustainable agricultural practices, and augmenting crop productivity as given by Afshar *et al.* (2014), Chandana *et al.* (2021) and WA Al-juthery *et al.* (2019).

4.5.7 Micro nutrients (mg kg⁻¹) concentration in sunflower seeds and stalk

Different levels of nano nitrogen, sulphur and zinc practice influence on micro nutrients like iron, manganese and copper in seed and stalk after harvest of sunflower crop is presented in Table 24-27.

Micro nutrients in post-harvest seed and stalk were non-significant ($p < 0.05$) by the influence of combination of nano nitrogen, sulphur and zinc. Among the treatments, highest micro nutrients concentration in sunflower seeds (70.70, 13.40 and 6.02 mg kg⁻¹ of iron, manganese and copper, respectively) and stalk (313.26, 55.32 and 13.48 mg kg⁻¹ of iron, manganese and copper, respectively) noticed in treatment T₁₂ (50% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) over treatment T₁ (absolute control) which recorded iron, manganese and copper of 68.20, 11.78 and 5.58 mg kg⁻¹ in seeds and 312.24, 54.34 and 12.86 mg kg⁻¹ in stalk, respectively.

However, in case of zinc concentration in seed and stalk of sunflower, significant ($p < 0.05$) difference was observed among treatments with the application of different levels of nano nitrogen, sulphur and zinc. Zinc content in post-harvest seed and stalk were significant ($p < 0.05$) and ranged from 25.74 to 30.85 mg kg⁻¹ in seeds and 103.48 to 109.16 mg kg⁻¹ in stalk. Least zinc content (25.74 mg kg⁻¹) in seeds and (103.48 mg kg⁻¹) in stalk was recorded in absolute control (T₁), because there were no fertilizer sources applied throughout the cropping season. Among the treatments highest zinc concentration in sunflower seeds (30.85 mg kg⁻¹) and stalk (109.16 mg kg⁻¹) noticed in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm) over treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) which recorded 27.49 mg kg⁻¹ in seeds and 105.64 mg kg⁻¹ in stalk.

The elevation of zinc concentration in sunflower seeds and stover, achieved through the application of varying levels of nano zinc as a foliar spray, can be attributed to a suite of key factors. Nano zinc, due to its highly soluble and readily accessible form, offers an efficient pathway for zinc uptake through foliar absorption by sunflower plants (Afshar *et al.*, 2014). This results in a heightened influx of zinc within the plant, consequently raising zinc concentrations in both the seeds and stover. Moreover, nano zinc minimizes losses often associated with traditional soil-applied zinc fertilizers, reducing the risk of leaching and immobilization as given by Al-Uthery *et al.* (2019)

Table 24. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of micronutrients (Fe, Zn and Mn) (mg kg⁻¹) in sunflower seeds after the harvest

Treatments	Details	Iron (mg kg ⁻¹)			Zinc (mg kg ⁻¹)			Manganese (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	70.29	66.12	68.20	27.56	23.92	25.74	12.05	11.52	11.78
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	70.43	66.36	68.39	29.91	25.06	27.49	12.19	11.65	11.92
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	70.86	66.30	68.58	30.93	25.02	27.98	12.35	11.70	12.02
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	71.02	66.74	68.88	30.81	24.91	27.86	12.45	11.95	12.20
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	69.53	68.15	68.84	31.02	25.21	28.11	12.83	12.16	12.50
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	70.36	66.23	68.30	31.15	25.53	28.34	12.97	12.49	12.73
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	70.64	66.59	68.62	31.64	25.69	28.66	12.50	11.74	12.12
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	71.16	66.88	69.02	31.39	25.45	28.42	12.69	12.12	12.41
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	71.66	67.14	69.40	32.84	26.61	29.73	13.24	12.64	12.94
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	72.44	67.88	70.16	32.95	26.92	29.93	13.44	12.33	12.89
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	72.70	68.32	70.51	33.07	27.53	30.30	13.65	12.83	13.24
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	73.00	68.40	70.70	33.51	27.14	30.33	13.78	13.02	13.40
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	71.87	67.55	69.71	33.29	27.64	30.46	13.05	12.16	12.61
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	72.30	67.74	70.02	33.74	27.96	30.85	13.10	12.52	12.81
	S.Em ±	2.03	1.91	1.97	0.9	0.74	0.82	0.37	0.35	0.36
	CD @ 5%	NS	NS	NS	2.62	2.16	2.39	NS	NS	NS

Table 25. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of micronutrients (Fe, Zn and Mn) (mg kg⁻¹) in sunflower stalk after the harvest

Treatments	Details	Iron (mg kg ⁻¹)			Zinc (mg kg ⁻¹)			Manganese (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	315.97	308.52	312.24	106.01	100.94	103.48	54.90	53.78	54.34
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	316.02	308.57	312.29	108.90	102.38	105.64	55.01	53.89	54.45
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.15	308.70	312.42	109.91	103.53	106.72	55.16	54.04	54.60
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.36	308.90	312.63	110.02	103.73	106.88	55.21	54.09	54.65
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.51	309.05	312.78	110.39	103.88	107.14	55.07	53.95	54.51
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.68	309.21	312.95	110.21	103.61	106.91	55.12	54.00	54.56
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.21	308.75	312.48	110.45	103.94	107.19	55.68	54.55	55.11
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	316.29	308.83	312.56	110.57	103.95	107.26	55.80	54.66	55.23
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	316.86	309.39	313.12	111.89	105.19	108.54	55.49	54.36	54.93
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	316.90	309.43	313.16	112.09	105.18	108.63	55.60	54.47	55.03
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	316.95	309.48	313.21	112.16	105.55	108.85	55.85	54.71	55.28
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	317.00	309.53	313.26	112.33	105.71	109.02	55.89	54.75	55.32
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	316.74	309.27	313.01	112.21	105.39	108.80	55.28	54.15	54.72
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	316.79	309.32	313.06	112.48	105.85	109.16	55.35	54.22	54.79
	S.Em ±	9.01	8.80	8.91	3.15	2.97	3.06	1.58	1.54	1.56
	CD @ 5%	NS	NS	NS	9.46	8.93	9.19	NS	NS	NS

Table 26. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of micronutrients (Cu and B) (mg kg⁻¹) in sunflower seeds after the harvest

Treatments	Details	Copper (mg kg ⁻¹)			Boron (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	5.81	5.34	5.58	78.35	78.90	78.63
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	5.85	5.48	5.66	80.95	79.91	80.43
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.87	5.41	5.64	81.68	79.73	80.70
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.97	5.51	5.74	82.29	79.30	80.80
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.99	5.66	5.82	82.94	77.97	80.46
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	6.02	5.64	5.83	82.56	77.56	80.06
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.90	5.49	5.70	83.06	79.09	81.07
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	5.93	5.55	5.74	82.98	78.95	80.97
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	6.15	5.80	5.97	83.19	78.15	80.67
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.16	5.72	5.94	82.85	81.06	81.96
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.19	5.80	5.99	83.88	79.80	81.84
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.23	5.81	6.02	83.39	81.28	82.33
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.05	5.61	5.83	83.02	79.93	81.47
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	6.07	5.59	5.83	82.81	80.02	81.42
	S.Em ±	0.17	0.15	0.16	2.35	2.27	2.31
	CD @ 5%	NS	NS	NS	NS	NS	NS

Table 27. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on concentration of micronutrients (Cu and B) (mg kg⁻¹) in sunflower stalk after the harvest

Treatments	Details	Copper (mg kg ⁻¹)			Boron (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	12.99	12.73	12.86	22.44	21.61	22.02
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	13.00	12.74	12.87	23.51	22.78	23.14
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.10	12.84	12.97	23.89	22.43	23.16
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.13	12.87	13.00	24.15	22.47	23.31
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.17	12.91	13.04	24.02	22.25	23.14
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.22	12.96	13.09	24.22	22.64	23.43
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.02	12.76	12.89	24.59	22.98	23.79
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.05	12.79	12.92	24.91	23.08	23.99
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	13.27	13.01	13.14	25.42	23.75	24.59
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.33	13.07	13.20	25.55	23.97	24.76
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.54	13.27	13.41	25.31	23.35	24.33
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.61	13.34	13.48	25.69	24.26	24.97
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.39	13.13	13.26	25.71	23.82	24.77
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.51	13.24	13.38	25.85	24.05	24.95
	S.Em ±	0.38	0.37	0.38	0.70	0.69	0.70
	CD @ 5%	NS	NS	NS	NS	NS	NS

The precision of foliar application ensures that zinc is delivered directly to the plant's leaves, where it can be rapidly absorbed and transported, promoting effective zinc supply and higher concentrations in the harvested parts (Patel *et al.*, 2019). The faster uptake kinetics associated with nano zinc further facilitate the accumulation of zinc. By targeting the plant directly, nano zinc foliar sprays reduce the risk of environmental contamination and offer a more sustainable approach to zinc supplementation as stated by Mahajan *et al.* (2013). The capacity to fine-tune zinc application levels ensures optimized nutrient management, while also alleviating the risk of zinc-induced plant stress. In summary, the application of nano zinc foliar sprays presents a promising strategy for enhancing zinc content in sunflower seeds and stover, promoting more sustainable agricultural practices and augmenting overall crop productivity. (Al-Uthery *et al.*, 2019; Badran and Savin, 2017; Mohsen *et al.*, 2016)

4.5.8 Boron (mg kg⁻¹) concentration in sunflower seeds and stalk.

The data on boron (mg kg⁻¹) content in sunflower seeds and stalk as influenced by different levels of nano nitrogen, sulphur and zinc treatment practice and presented in Table 26 and 27. Boron percentage in post-harvest seed and stalk were non-significant ($p < 0.05$) on the influence of combination of nano nitrogen, sulphur and zinc. Among the treatments numerically highest boron concentration in sunflower seeds (82.33 mg kg⁻¹) and in stalk (24.97 mg kg⁻¹) noticed in treatment T₁₂ (50% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) over treatment T₁ (absolute control) which recorded 78.63 mg kg⁻¹ in seeds and 22.02 mg kg⁻¹ in stalk.

4.6 Effect of different levels of nano nitrogen, sulphur and zinc on nutrients uptake by sunflower

4.6.1 Nitrogen uptake (kg ha⁻¹)

Data on nitrogen uptake by seeds and stalk of sunflower showed significant ($p < 0.05$) variation due to different levels of nano nitrogen, sulphur and zinc practice and are presented in Table 28.

Results showed that significant ($p < 0.05$) variation in nitrogen uptake by seeds with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) which recorded higher nitrogen uptake in seeds of sunflower *i.e.*, 92.53 kg ha⁻¹ that was on par with

treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) which recorded 88.29 kg ha⁻¹ when compare to treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) recorded 64.04 kg ha⁻¹. Absolute control recorded significantly ($p<0.05$) lower nitrogen uptake by seeds (36.04 kg ha⁻¹).

In case of stalk, treatment which had 75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm (T₈) recorded significantly ($p<0.05$) higher nitrogen uptake (40.28 kg ha⁻¹) that was on par with treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) which recorded 39.35 kg ha⁻¹ over treatment T₂ (26.45 kg ha⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Absolute control recorded lower nitrogen uptake by stalk (14.75kg ha⁻¹).

The total nitrogen uptake varied significantly ($p<0.05$) in treatment receiving 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) which recorded 132.23 kg ha⁻¹. While, it was on par with 75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm (T₈) which recorded 128.57 kg ha⁻¹. Whereas, lower total nitrogen uptake was observed in absolute control (50.79 kg ha⁻¹).

Nitrogen uptake by seeds and stalk of sunflower showed significant ($p<0.05$) variation due to different levels of nano nitrogen, sulphur and zinc foliar spray. The increase in nitrogen concentration in the seeds and stover of sunflower with the application of different levels of nano nitrogen as a foliar spray can be attributed to several key factors like reduced losses, precision application, enhanced nutrient mobility, faster uptake, optimized nutrient management and reduced nitrogen stress as given by Taheri *et al.* (2015).

Nano nitrogen, being in a highly soluble and readily available form, can be more efficiently taken up by plant leaves through foliar absorption. This can result in a greater influx of nitrogen into the plant, subsequently leading to higher nitrogen concentrations in both the seeds and stover. Badran and Savin (2017) mentioned that traditional nitrogen fertilizers applied to the soil can be subject to leaching, volatilization, or denitrification, leading to nutrient losses. Nano nitrogen as a foliar spray can reduce such losses, as it is directly applied to the plant surface, minimizing the risk of nutrient runoff or gaseous losses. This improved nutrient retention can contribute to higher nitrogen concentrations in the crop as given by Shailesh *et al.* (2013).

Table 28: Uptake of Nitrogen (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Nitrogen (kg ha⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	36.74	35.34	36.04	15.18	14.34	14.75	51.92	49.67	50.79
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	65.51	62.58	64.04	27.43	25.48	26.45	92.94	88.05	90.48
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	57.57	55.56	56.56	24.35	23.39	23.87	81.92	78.95	80.43
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	63.95	60.54	62.24	26.35	24.98	25.66	90.30	85.52	87.90
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	76.15	73.29	74.71	32.41	32.02	32.22	108.56	105.31	106.94
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	84.07	80.53	82.30	36.87	35.00	35.93	120.95	115.54	118.23
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	80.50	78.13	79.31	33.28	31.15	32.21	113.78	109.28	111.52
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	90.77	85.83	88.29	41.37	39.20	40.28	132.14	125.03	128.57
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	62.34	60.12	61.23	26.54	25.69	26.12	88.88	85.81	87.35
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	67.18	64.14	65.66	29.72	28.52	29.12	96.90	92.67	94.78
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	77.72	73.43	75.56	32.65	30.80	31.72	110.37	104.22	107.28
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	84.73	80.58	82.65	37.69	35.69	36.68	122.42	116.27	119.33
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	84.53	80.95	82.73	35.10	33.62	34.36	119.63	114.56	117.09
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	95.02	90.05	92.53	40.05	39.35	39.70	135.08	129.39	132.23
	S.Em ±	2.01	1.92	1.96	0.86	0.82	0.84	2.86	2.74	2.80
	CD @ 5%	5.83	5.58	5.70	2.49	2.39	2.44	8.32	7.96	8.14

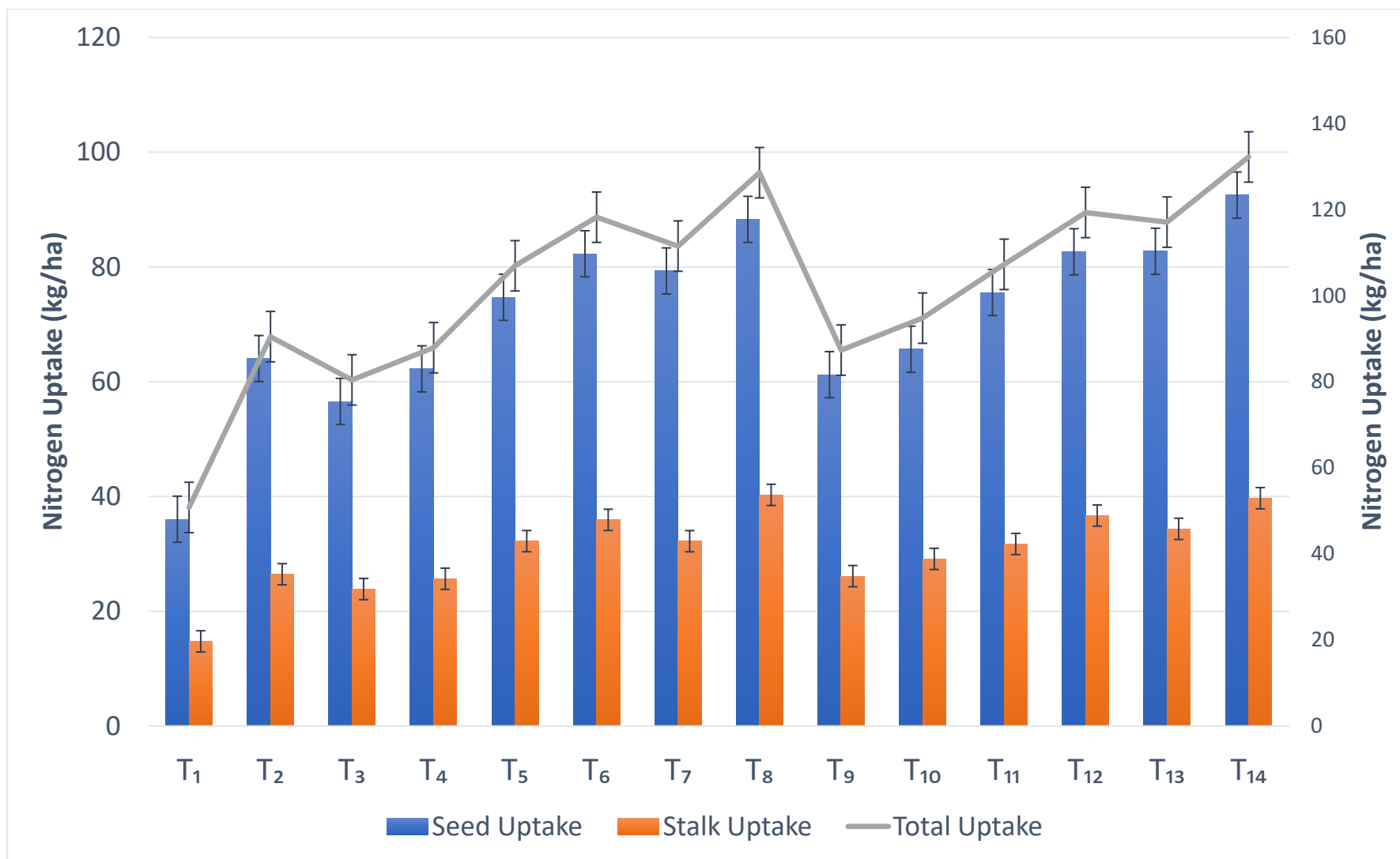


Fig. 2: Uptake of Nitrogen (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Foliar spraying with nano nitrogen allows for precise and targeted nutrient delivery. It enables growers to apply nitrogen directly to the leaves, where it can be readily absorbed and translocated within the plant. This precision can result in a more effective nitrogen supply, promoting higher nitrogen concentrations in the seeds and stover. Nano-sized particles can improve the mobility of nutrients within the plant. They can move more easily through cell walls and membranes, facilitating the translocation of nitrogen to various plant parts, including the seeds and stover as stated by Sedgi *et al.* (2013). The application of different levels of nano nitrogen as a foliar spray allows for precise control over the nitrogen supply to the plant. This enables to fine-tune the nutrient application based on the specific needs of the crop at different growth stages, which can lead to higher nitrogen concentrations in the harvested seeds and stover as outlined by Jhanzab *et al.* (2015), Sedgi *et al.* (2013) and Mahajan *et al.* (2013).

4.6.2 Phosphorus uptake (kg ha^{-1})

The data pertaining to phosphorus uptake by sunflower showed significant ($p < 0.05$) variation as influenced by application of different levels of nano nitrogen, sulphur and zinc practice and are presented in Table 29.

Results revealed that application of 75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm+ nZn @500ppm (T_{14}) showed higher phosphorus uptake by seed and stalk (22.85 and 12.25 kg ha^{-1} , respectively) over treatment which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (17.58 and 8.82 kg ha^{-1}). Treatment T_8 showed on par results on phosphorus uptake by seed and stalk with the treatment having 75% RDN + nU @ 4 ml/l + 50% ZnSO_4 + nS @ 100ppm + nZn @250ppm (22.00 and 11.48 kg ha^{-1} , respectively). On the other hand, significantly ($p < 0.05$) lowest phosphorus uptake (10.69 and 5.05 kg ha^{-1} by seed and stalk, respectively) was recorded in absolute control (T_1).

Data on total phosphorus uptake showed significant ($p < 0.05$) variation due to influenced by application of different levels of nano nitrogen, sulphur and zinc practice and are presented in Table 14. Results showed that significant ($p < 0.05$) higher total phosphorus uptake was observed in treatment with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm+ nZn @500ppm (T_{14}) which recorded 35.10 kg ha^{-1} , which was on par with treatment T_8 (75% RDN + nU @ 4 ml/l + 50% ZnSO_4 + nS @ 100ppm + nZn @250ppm) which recorded 33.48 kg ha^{-1} over treatment which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (26.40 kg ha^{-1}).

Table 29: Uptake of Phosphorus (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Phosphorus (kg ha⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	10.84	10.53	10.69	5.27	4.83	5.05	16.11	15.36	15.74
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	18.03	17.14	17.58	9.14	8.49	8.82	27.17	25.63	26.40
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	15.50	14.94	15.22	8.02	6.89	7.44	23.51	21.83	22.66
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	16.30	15.52	15.91	8.23	7.58	7.90	24.54	23.10	23.81
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	19.75	18.99	19.37	10.15	9.04	9.59	29.90	28.03	28.96
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	20.85	19.50	20.17	10.89	10.06	10.47	31.74	29.56	30.64
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	21.22	20.04	20.63	10.68	9.58	10.13	31.90	29.62	30.75
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.63	21.38	22.00	11.95	11.01	11.48	34.58	32.39	33.48
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	16.82	16.03	16.42	9.07	8.67	8.87	25.89	24.70	25.29
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	17.22	16.31	16.76	8.74	9.16	8.96	25.96	25.47	25.72
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	20.50	19.35	19.92	10.88	10.14	10.51	31.38	29.48	30.43
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	21.59	20.26	20.92	11.13	10.66	10.90	32.73	30.92	31.82
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	22.40	21.20	21.79	11.70	11.21	11.45	34.10	32.40	33.25
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	23.88	21.84	22.85	12.43	12.07	12.25	36.31	33.91	35.10
	S.Em ±	0.52	0.49	0.51	0.27	0.26	0.27	0.79	0.75	0.77
	CD @ 5%	1.52	1.44	1.48	0.78	0.74	0.76	2.31	2.18	2.24

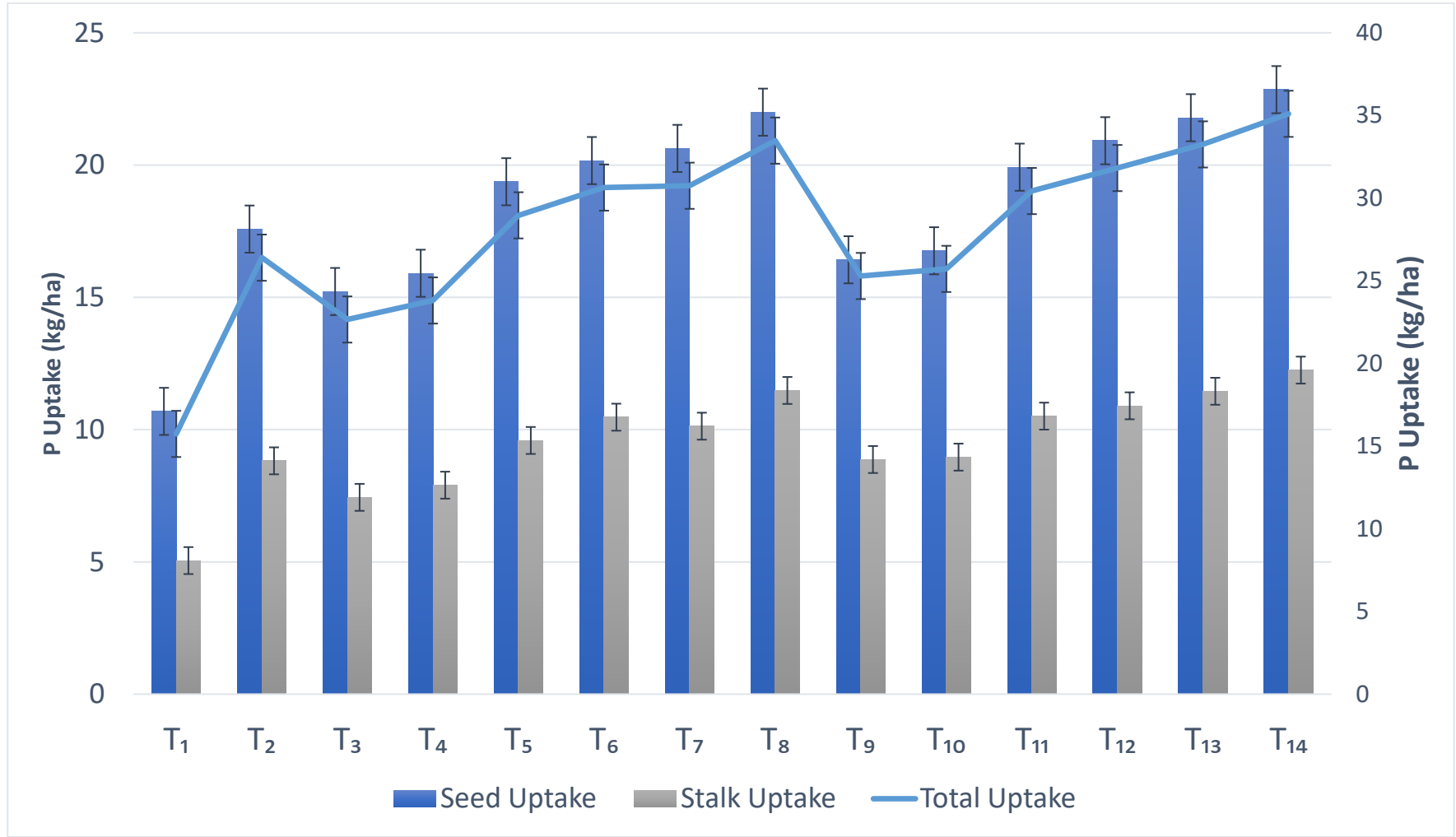


Fig. 3: Uptake of Phosphorus (kg ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

4.6.3 Potassium uptake (kg ha^{-1})

Data representing potassium uptake (kg ha^{-1}) by sunflower crop as influenced by application of different levels of nano nitrogen, sulphur and zinc practice is presented in Table 30.

Significantly ($p < 0.05$) higher potassium uptake by seeds (26.87 kg ha^{-1}) and stalk (61.71 kg ha^{-1}) was recorded in treatment $75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{14}) followed by treatment T_8 ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 50\% \text{ ZnSO}_4 + \text{nS @ } 100\text{ppm} + \text{nZn @ } 250\text{ppm}$) which recorded 25.16 and 60.75 kg ha^{-1} in seeds and stalk, respectively over treatment Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (20.53 and 48.58 kg ha^{-1} in seeds and stalk, respectively). In contrast, significantly ($p < 0.05$) lower potassium uptake (12.29 and 27.71 kg ha^{-1} in seeds and stalk, respectively) was recorded in treatment T_1 i.e., absolute control.

Total potassium uptake was recorded (88.58 kg ha^{-1}) significantly ($p < 0.05$) higher with the application of $75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{14}) which was on par with treatment T_8 ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 50\% \text{ ZnSO}_4 + \text{nS @ } 100\text{ppm} + \text{nZn @ } 250\text{ppm}$) which recorded 85.91 kg ha^{-1} over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (16.99 kg ha^{-1}) recorded total potassium uptake (69.10 kg ha^{-1}).

4.6.4 Calcium uptake (kg ha^{-1}) by sunflower.

Data on calcium uptake (kg ha^{-1}) by sunflower crop as influenced by soil application of different levels of nano nitrogen, sulphur and zinc practices is represented in Table 31.

Results revealed that soil application of $75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{14}) showed higher calcium uptake by seed (2.89 kg ha^{-1}) which was on par with treatment $75\% \text{ RDN} + \text{nU @ } 2 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{13}) which recorded 2.72 kg ha^{-1} over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (1.87 kg ha^{-1}). On the other hand, significantly ($p < 0.05$) lowest calcium uptake (1.19 kg ha^{-1}) by seed was recorded in absolute control (T_1).

Table 30: Uptake of Potassium (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Potassium (kg ha⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	12.53	12.05	12.29	28.45	26.98	27.71	40.98	39.03	40.00
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	21.03	20.02	20.53	49.38	47.77	48.58	70.42	67.80	69.10
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	17.88	17.27	17.57	41.62	40.42	41.02	59.50	57.69	58.59
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	18.99	17.91	18.45	44.46	42.30	43.38	63.45	60.21	61.82
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	23.04	22.19	22.61	53.11	50.85	51.98	76.15	73.04	74.59
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	24.28	23.05	23.66	56.57	53.90	55.23	80.85	76.95	78.89
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	24.22	23.42	23.82	55.47	53.51	54.49	79.69	76.93	78.31
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	26.11	24.23	25.16	62.05	59.45	60.75	88.16	83.68	85.91
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	19.38	18.70	19.04	45.02	43.35	44.19	64.40	62.05	63.23
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	20.25	19.06	19.65	47.20	45.81	46.50	67.45	64.87	66.15
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	24.10	22.79	23.44	54.42	53.02	53.72	78.52	75.81	77.17
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	24.88	24.08	24.48	58.24	55.36	56.80	83.12	79.45	81.28
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	25.53	24.69	25.11	58.93	56.44	57.69	84.46	81.13	82.80
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	27.48	26.25	26.87	63.07	60.36	61.71	90.55	86.61	88.58
	S.Em ±	0.61	0.58	0.60	1.40	1.35	1.38	2.01	1.93	1.97
	CD @ 5%	1.76	1.69	1.73	4.08	3.92	4.00	5.84	5.60	5.72

Table 31: Uptake of Calcium (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Calcium (kg ha ⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	1.20	1.05	1.19	11.80	10.07	10.92	13.01	11.12	12.11
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	2.00	1.73	1.87	21.95	19.11	20.51	23.95	20.84	22.38
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.87	1.83	1.85	18.19	15.87	17.01	20.06	17.69	18.86
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.97	1.71	1.84	19.43	16.73	18.06	21.40	18.44	19.90
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2.41	2.13	2.27	23.43	20.34	21.86	25.84	22.47	24.14
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2.29	2.22	2.25	25.14	21.72	23.40	27.43	23.94	25.66
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2.54	2.03	2.28	24.65	21.57	23.09	27.19	23.59	25.37
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2.74	2.61	2.67	27.58	23.78	25.65	30.31	26.39	28.32
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	2.19	1.78	1.98	19.82	17.02	18.40	22.02	18.80	20.38
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	2.08	1.65	1.86	20.63	17.98	19.29	22.71	19.63	21.15
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	2.48	2.15	2.31	24.19	21.05	22.60	26.66	23.20	24.91
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	2.82	2.48	2.64	25.69	22.15	23.89	28.51	24.62	26.54
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	2.89	2.56	2.72	26.00	22.41	24.18	28.89	24.97	26.90
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	3.08	2.70	2.89	27.62	24.14	25.86	30.71	26.84	28.75
	S.Em ±	0.06	0.06	0.06	0.62	0.53	0.58	0.68	0.59	0.64
	CD @ 5%	0.19	0.16	0.17	1.79	1.55	1.67	1.98	1.72	1.85

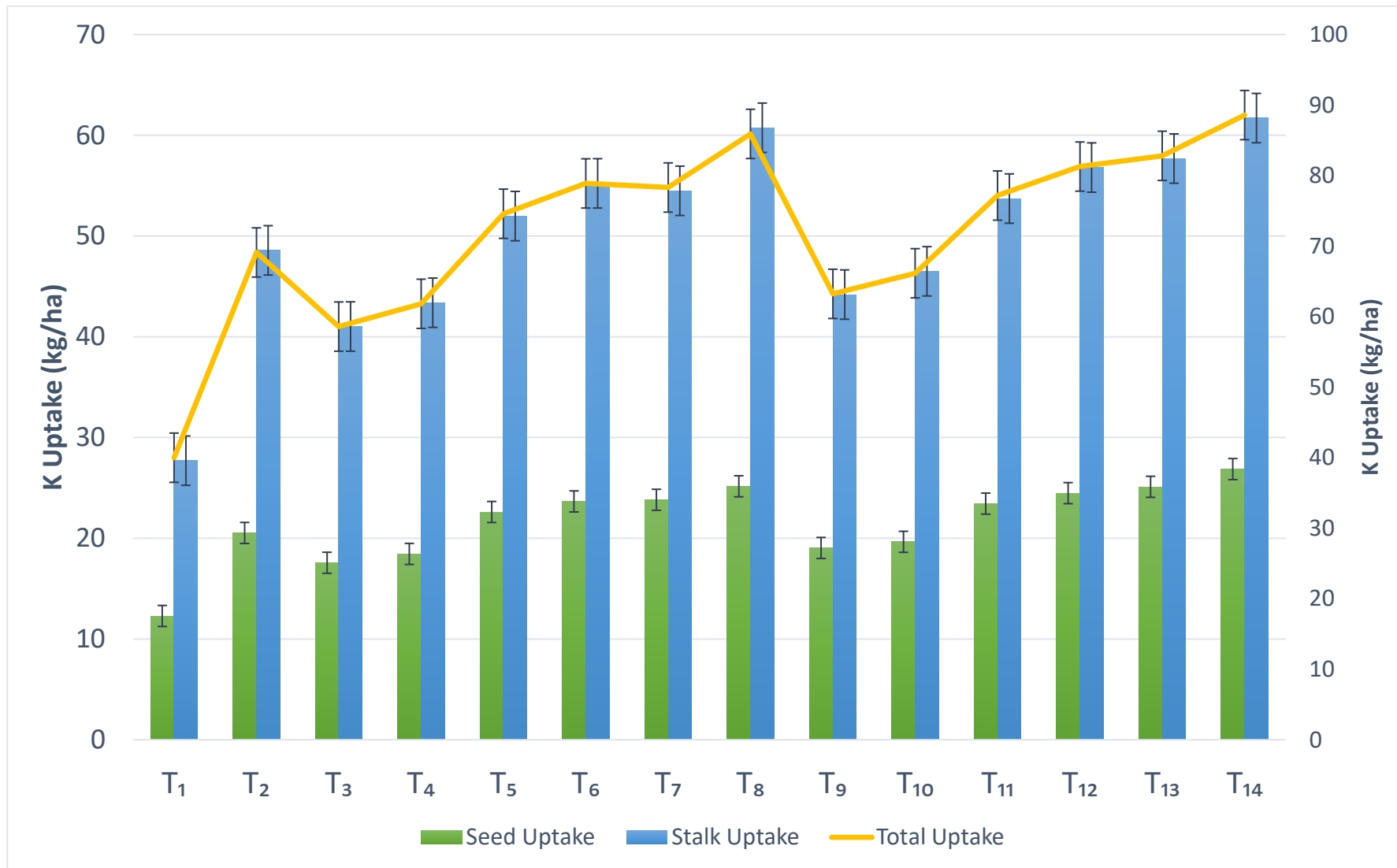


Fig. 4: Uptake of Potassium (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

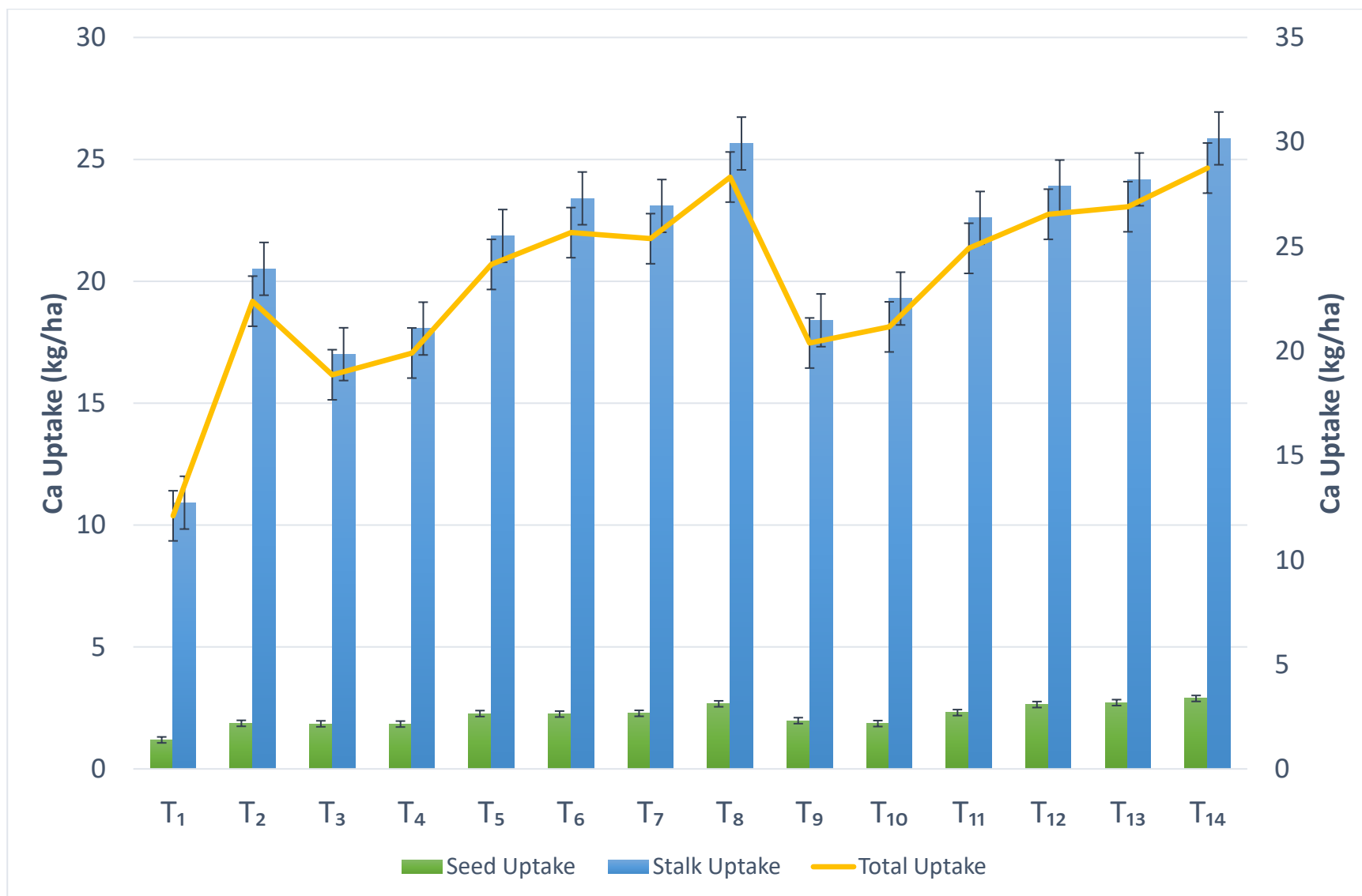


Fig. 5: Uptake of Calcium (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Results revealed that soil application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) showed higher calcium uptake by stalk (25.86 kg ha⁻¹) which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) which recorded 25.65 kg ha⁻¹ over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (20.51 kg ha⁻¹). On the other hand, significantly (p<0.05) lowest calcium uptake (10.92 kg ha⁻¹) by stalk was recorded in absolute control (T₁).

Data on total calcium uptake showed significant (p<0.05) variation due to the influence of soil application of different levels of nano nitrogen, sulphur and zinc practice and are presented in Table 13. Results showed that significant (p<0.05) higher total calcium uptake was observed in treatment with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) which recorded 28.75 kg ha⁻¹, which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) which recorded 28.32 kg ha⁻¹ over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (22.38 kg ha⁻¹).

4.6.5 Magnesium uptake (kg ha⁻¹) by sunflower.

Different levels of nano nitrogen, sulphur and zinc practices influenced on magnesium uptake (kg ha⁻¹) by sunflower after harvest of crop presented in Table 32.

Significantly (p<0.05) higher magnesium uptake by seed (4.77 kg ha⁻¹) and stalk (14.29 kg ha⁻¹) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) followed by treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (4.50 and 13.50 kg ha⁻¹ in seeds and stalk, respectively) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 3.73 and 10.79 kg ha⁻¹ in seeds and stalk, respectively. In contrast, significantly (p<0.05) lower magnesium uptake (2.08 and 5.84 kg ha⁻¹ in seeds and stalk, respectively) was recorded in absolute control.

Total magnesium uptake was recorded significantly (p<0.05) higher with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (19.06 kg ha⁻¹) over all the treatments, which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ +

Table 32: Uptake of Magnesium (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Magnesium (kg ha ⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	2.17	1.99	2.08	6.11	5.84	5.98	8.28	7.83	8.05
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	3.81	3.66	3.73	10.97	10.62	10.79	14.78	14.27	14.53
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.07	2.99	3.03	9.25	8.68	8.96	12.31	11.67	11.99
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.22	3.24	3.23	9.88	9.79	9.84	13.10	13.03	13.07
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	3.95	3.63	3.79	12.11	10.92	11.51	16.06	14.55	15.29
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	4.12	3.77	3.94	12.99	12.07	12.52	17.11	15.83	16.47
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	4.18	3.83	4.00	12.74	11.98	12.36	16.91	15.81	16.36
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	4.48	4.51	4.50	14.25	12.77	13.50	18.73	17.28	18.00
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	3.49	3.21	3.35	10.42	8.99	9.69	13.91	12.20	13.04
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	3.58	3.12	3.34	10.84	9.50	10.16	14.42	12.62	13.51
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	4.39	3.87	4.13	12.90	12.09	12.49	17.29	15.95	16.62
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	4.46	3.83	4.14	13.70	12.71	13.20	18.16	16.54	17.34
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	4.58	4.43	4.49	13.87	12.45	13.15	18.44	16.88	17.65
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	5.14	4.42	4.77	14.73	13.86	14.29	19.87	18.28	19.06
	S.Em ±	0.11	0.10	0.10	0.32	0.30	0.31	0.43	0.39	0.41
	CD @ 5%	0.31	0.28	0.30	0.94	0.86	0.90	1.25	1.15	1.20

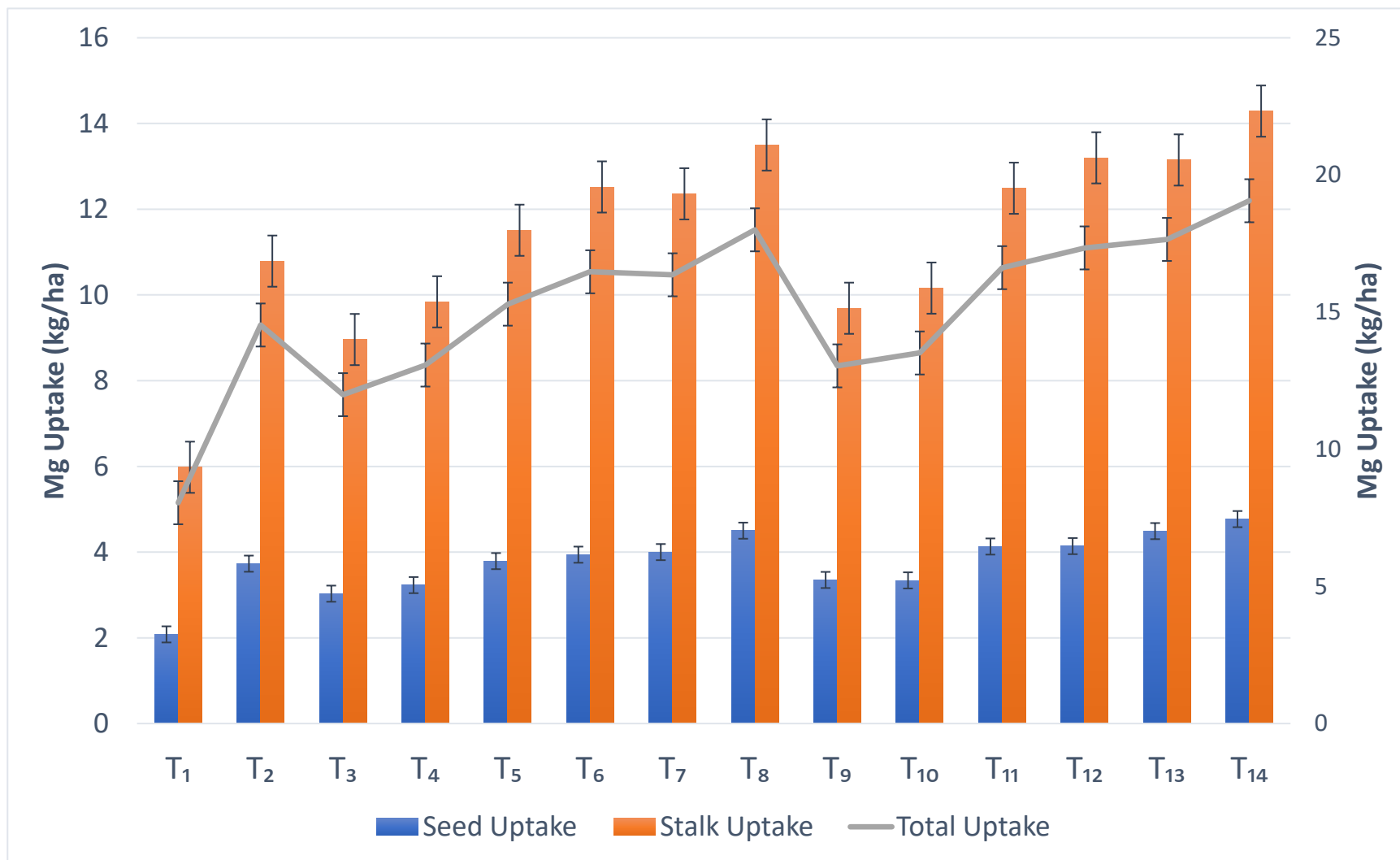


Fig. 6: Uptake of Magnesium (kg ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

nS @ 100ppm + nZn @250ppm) (18.00 kg ha^{-1}) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (14.53 kg ha^{-1}). Whereas, lower magnesium uptake was recorded in untreated plot (8.05 kg ha^{-1}).

4.6.6 Sulphur uptake (kg ha^{-1}) by sunflower.

Data representing sulphur uptake (kg ha^{-1}) by sunflower as influenced by soil application of different levels of nano nitrogen, sulphur and zinc practice is represented in Table 33.

Significantly ($p < 0.05$) higher sulphur uptake by seeds (13.31 kg ha^{-1}) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) over all treatments, followed by treatment 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₃) which recorded 12.32 kg ha^{-1} , when compared to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (8.45 kg ha^{-1}). In contrast significantly ($p < 0.05$), lower sulphur uptake (4.63 kg ha^{-1}) was recorded in absolute control (T₁).

Significantly ($p < 0.05$) higher sulphur uptake by stalk (10.21 kg ha^{-1}) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) over all treatments, followed by treatment 50% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₂) which recorded 9.22 kg ha^{-1} , when compared to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (5.40 kg ha^{-1}). In contrast significantly ($p < 0.05$), lower sulphur uptake (2.68 kg ha^{-1}) was recorded in absolute control (T₁).

Total sulphur uptake was recorded significantly ($p < 0.05$) higher with the application of treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (23.52 kg ha^{-1}) over all the treatments. However, it is on par with treatment 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₃) (21.01 kg ha^{-1}) when compare to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (13.84 kg ha^{-1}). Whereas, lower sulphur uptake was recorded in untreated plot *i.e.*, treatment T₁ (7.31 kg ha^{-1}).

The increase in sulphur uptake in the seeds and stover of sunflower with the application of different levels of nano sulphur as a foliar spray can be attributed to several key factors like Nano sulphur, when used as a foliar spray, provides highly soluble and plant-accessible sulphur, enhancing the efficiency of sulphur uptake by sunflower plants. This leads to increased sulphur

Table 33: Uptake of Sulphur (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Sulphur (kg ha ⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	4.94	4.33	4.63	2.95	2.42	2.68	7.89	6.75	7.31
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	8.81	8.09	8.45	5.85	4.95	5.40	14.67	13.04	13.84
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	7.83	6.97	7.40	5.24	4.79	5.01	13.08	11.76	12.41
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	8.42	7.85	8.13	5.60	5.05	5.32	14.02	12.90	13.45
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.31	9.60	9.95	7.03	6.78	6.90	17.34	16.38	16.86
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	11.23	10.15	10.68	7.12	7.24	7.19	18.35	17.39	17.87
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	11.07	10.36	10.71	7.40	7.19	7.29	18.47	17.55	18.00
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	12.19	10.69	11.43	8.27	7.49	7.88	20.46	18.18	19.30
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	9.51	8.90	9.20	6.72	6.42	6.57	16.23	15.33	15.77
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	9.65	8.73	9.19	6.99	7.13	7.06	16.64	15.86	16.25
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	11.94	11.18	11.56	8.87	8.19	8.52	20.81	19.37	20.08
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	12.21	10.93	11.56	9.42	9.02	9.22	21.63	19.96	20.78
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	12.76	11.88	12.32	8.67	8.72	8.70	21.43	20.60	21.01
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	13.61	13.00	13.31	10.13	10.28	10.21	23.74	23.29	23.52
	S.Em ±	0.28	0.26	0.27	0.20	0.19	0.20	0.48	0.46	0.47
	CD @ 5%	0.83	0.76	0.79	0.58	0.56	0.57	1.41	1.32	1.36

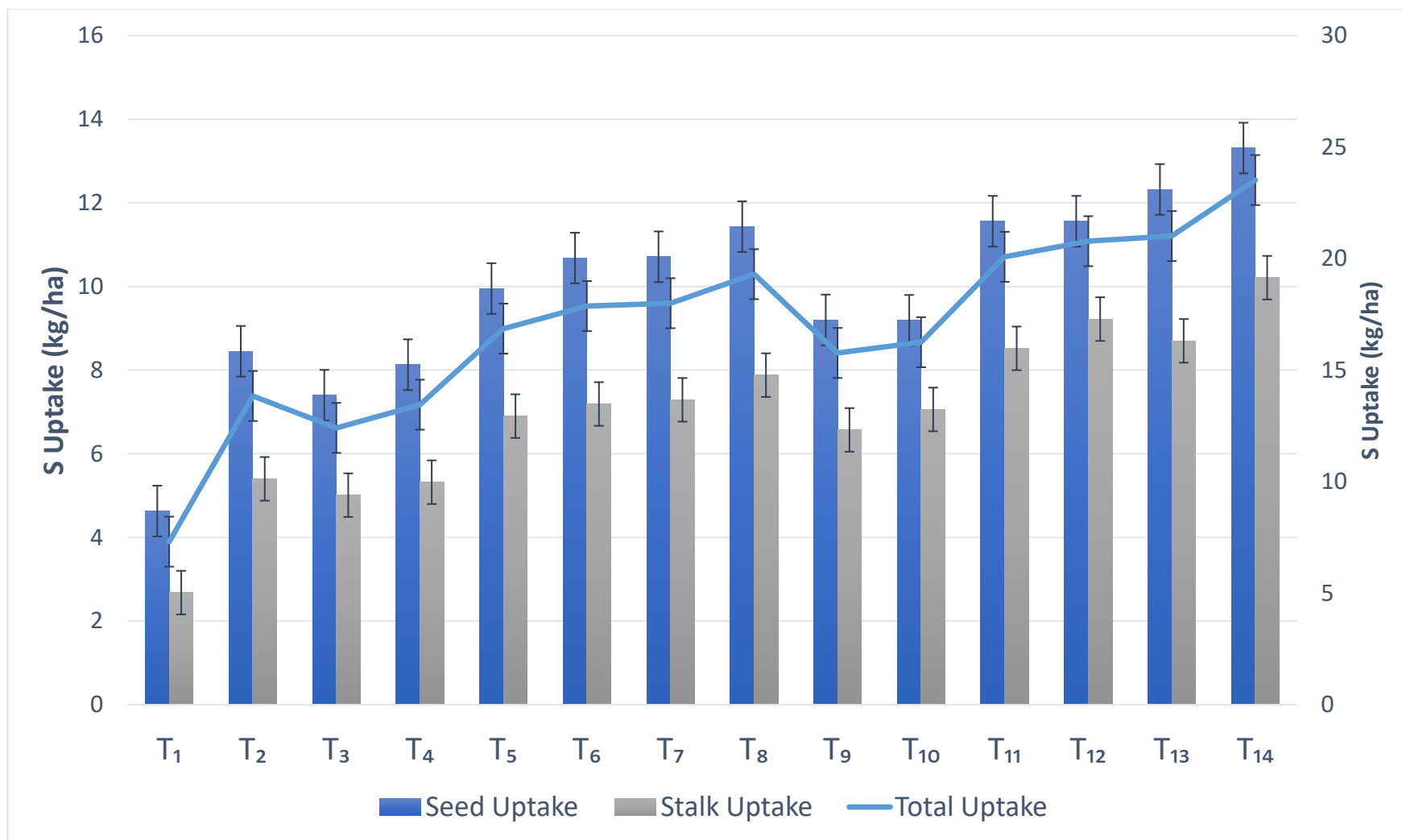


Fig. 7: Uptake of sulphur (kg ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

influx and higher concentrations in seeds and stover as indicated by Jhanzab *et al.* (2015). Conventional sulphur fertilizers may be susceptible to leaching and atmospheric losses, but nano sulphur foliar sprays directly apply to the plant, minimizing these losses and ensuring higher sulphur retention in plant tissues. This precise and targeted delivery of sulphur to the plant minimizes wastage and promotes higher sulphur concentrations in seeds and stover (Mandal *et al.*, 2015). Nano-sized sulphur particles also improve mobility within the plant, facilitating the translocation of sulphur to various parts, including seeds and stover as mentioned by Abasalt *et al.* (2015); Farnia and Omid (2015).

Fertilizers based on nanotechnology frequently have quicker assimilation and absorption kinetics. The plant's fast absorption of sulphur might lead to a quicker build-up of sulphur in the seeds and stover (Sedgi *et al.*, 2013). The environmental effect of using sulphur fertilizer may be lessened by nano sulphur foliar sprays. They reduce too much sulphur in the soil, which can cause problems for the ecosystem like acidification of the soil as designated by Taheri *et al.* (2015). Growers may precisely regulate the sulphur supply to the plant depending on its unique needs at various development stages by using various concentrations of nano sulphur as a foliar spray. This may result in greater sulphur levels in the stover and seeds that are collected as noted by Patel *et al.* (2019). Traditional applications of sulphur may occasionally result in nutritional imbalances and stress in plants. Nano sulphur, when used appropriately, can mitigate such stress, allowing plants to efficiently utilize the nutrient for growth and development, resulting in higher sulphur concentrations in the crop. These results were in line with Burmana *et al.* (2013), Tarafdar *et al.* (2012a), Fan *et al.* (2012) and Ma *et al.* (2010).

4.6.7 Iron uptake (g ha^{-1}) by sunflower.

Data representing iron uptake (g ha^{-1}) by sunflower crop as influenced by application of different levels of nano nitrogen, sulphur and zinc practice is presented in Table 34.

Iron uptake, significantly ($p < 0.05$) higher (175.81 and $1420.48 \text{ g ha}^{-1}$ in seeds and stalk, respectively) was recorded in treatment $75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{14}) followed by treatment T_8 ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 50\% \text{ ZnSO}_4 + \text{nS @ } 100\text{ppm} + \text{nZn @ } 250\text{ppm}$) which recorded 167.79 and $1406.54 \text{ g ha}^{-1}$ in seeds and stalk, respectively over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (134.35 and $1123.71 \text{ g ha}^{-1}$ in seeds and stalk, respectively). In contrast, significantly ($p < 0.05$)

Table 34: Uptake of Iron (g ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Iron (g ha ⁻¹)										
	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	84.67	77.38	80.99	665.96	621.09	643.35	750.63	698.47	724.34
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	141.09	127.76	134.35	1155.97	1091.89	1123.71	1297.06	1219.65	1258.06
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	120.69	110.08	115.34	974.65	924.19	949.25	1095.34	1034.27	1064.59
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	127.22	113.82	120.43	1041.85	975.13	1008.24	1169.07	1088.96	1128.67
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	152.58	139.00	145.72	1235.96	1164.15	1199.80	1388.54	1303.15	1345.52
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	161.19	146.80	153.92	1326.94	1243.66	1284.99	1488.14	1390.46	1438.91
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	162.95	149.94	156.39	1299.26	1233.03	1265.93	1462.21	1382.97	1422.32
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	176.97	158.85	167.79	1453.77	1360.04	1406.54	1630.74	1518.89	1574.34
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	131.00	119.57	125.23	1064.64	993.50	1028.79	1195.64	1113.07	1154.03
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	137.09	124.41	130.68	1108.08	1049.88	1078.79	1245.17	1174.29	1209.47
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	163.77	146.87	155.20	1277.62	1206.49	1241.81	1441.39	1353.35	1397.01
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	171.34	153.95	162.53	1357.55	1269.38	1313.13	1528.88	1423.33	1475.66
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	173.09	157.35	165.13	1372.52	1283.49	1327.66	1545.61	1440.84	1492.80
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	185.67	166.21	175.81	1458.46	1382.99	1420.48	1644.13	1549.21	1596.29
	S.Em ±	4.09	3.71	3.90	32.83	30.91	31.86	36.92	34.62	35.76
	CD @ 5%	11.89	10.79	11.33	95.44	89.85	92.62	107.33	100.63	103.95

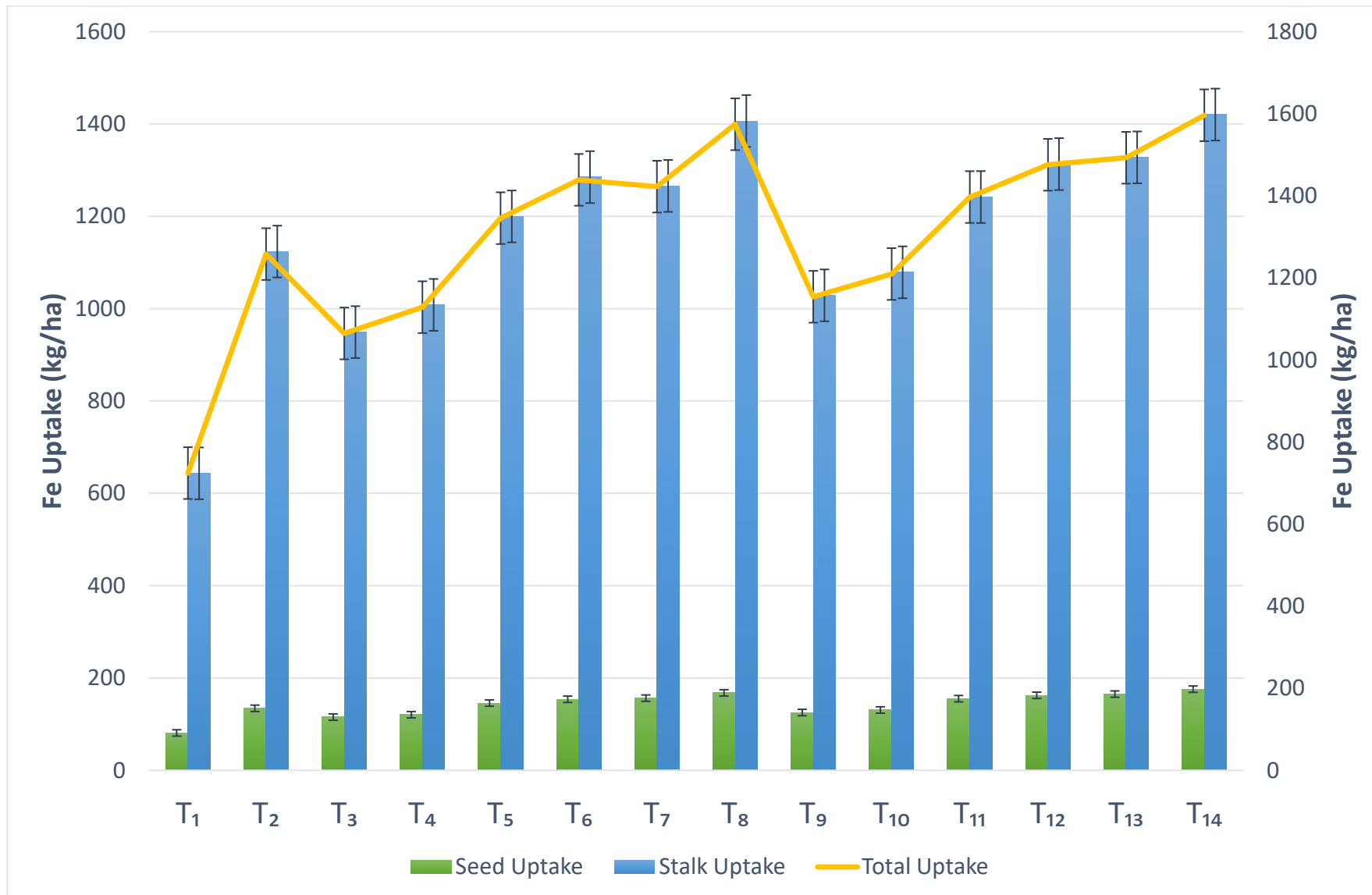


Fig. 8: Uptake of iron (g ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

lower iron uptake (80.99 and 643.35 g ha⁻¹ in seeds and stalk, respectively) was recorded in treatment T₁ i.e., absolute control.

Total iron uptake was recorded significantly ($p < 0.05$) higher with the application of receiving 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (1596.29 g ha⁻¹) which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) which recorded 1574.34 g ha⁻¹ when compare to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) recorded less total iron uptake (1258.06 g ha⁻¹).

4.6.8 Manganese uptake (g ha⁻¹) by sunflower.

Data representing manganese uptake (g ha⁻¹) by sunflower crop as influenced by soil application of different levels of nano nitrogen, sulphur and zinc practice is presented in Table 35.

Manganese uptake by seeds significantly ($p < 0.05$) higher (32.17 g ha⁻¹) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) followed by treatment 50% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₂) which recorded 30.80 g ha⁻¹ over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) (23.42 g ha⁻¹). In contrast, significantly ($p < 0.05$) lower manganese uptake (13.99 g ha⁻¹) was recorded in treatment T₁ i.e., absolute control.

In case of stalk, significantly ($p < 0.05$) higher manganese uptake was recorded in treatment receiving 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (248.59 g ha⁻¹) which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (248.55 g ha⁻¹) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) recorded less manganese uptake by stalk (195.92 g ha⁻¹).

Total manganese uptake was recorded significantly ($p < 0.05$) higher with the application of receiving 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (280.76 g ha⁻¹) which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) which recorded 278.71 g ha⁻¹, when compare to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) recorded less total manganese uptake (219.34 g ha⁻¹).

Table 35: Uptake of Manganese (g ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Manganese (g ha ⁻¹)										
	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	14.52	13.48	13.99	115.71	108.27	111.96	130.23	121.75	125.96
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	24.41	22.44	23.42	201.22	190.69	195.92	225.63	213.13	219.34
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	21.03	19.42	20.22	170.05	161.78	165.89	191.08	181.20	186.11
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.30	20.38	21.33	181.82	170.74	176.24	204.12	191.12	197.57
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	28.16	25.94	27.04	215.05	203.22	209.09	243.21	229.16	236.14
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	29.71	27.68	28.69	230.96	217.18	224.02	260.67	244.86	252.71
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	28.83	26.44	27.63	228.78	217.84	223.28	257.61	244.28	250.90
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	31.56	28.80	30.16	256.47	240.73	248.55	288.03	269.52	278.71
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	24.20	22.52	23.35	186.44	174.56	180.46	210.65	197.08	203.81
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	25.43	22.60	24.00	194.41	184.81	189.58	219.85	207.41	213.58
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	30.74	27.58	29.14	225.13	213.30	219.18	255.87	240.87	248.31
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	32.34	29.29	30.80	239.35	224.54	231.89	271.69	253.84	262.69
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	31.43	28.34	29.86	239.54	224.74	232.09	270.97	253.08	261.96
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	33.66	30.71	32.17	254.82	242.44	248.59	288.48	273.14	280.76
	S.Em ±	0.74	0.68	0.71	5.75	5.43	5.59	6.49	6.11	6.30
	CD @ 5%	2.16	1.97	2.07	16.71	15.78	16.24	18.87	17.75	18.31

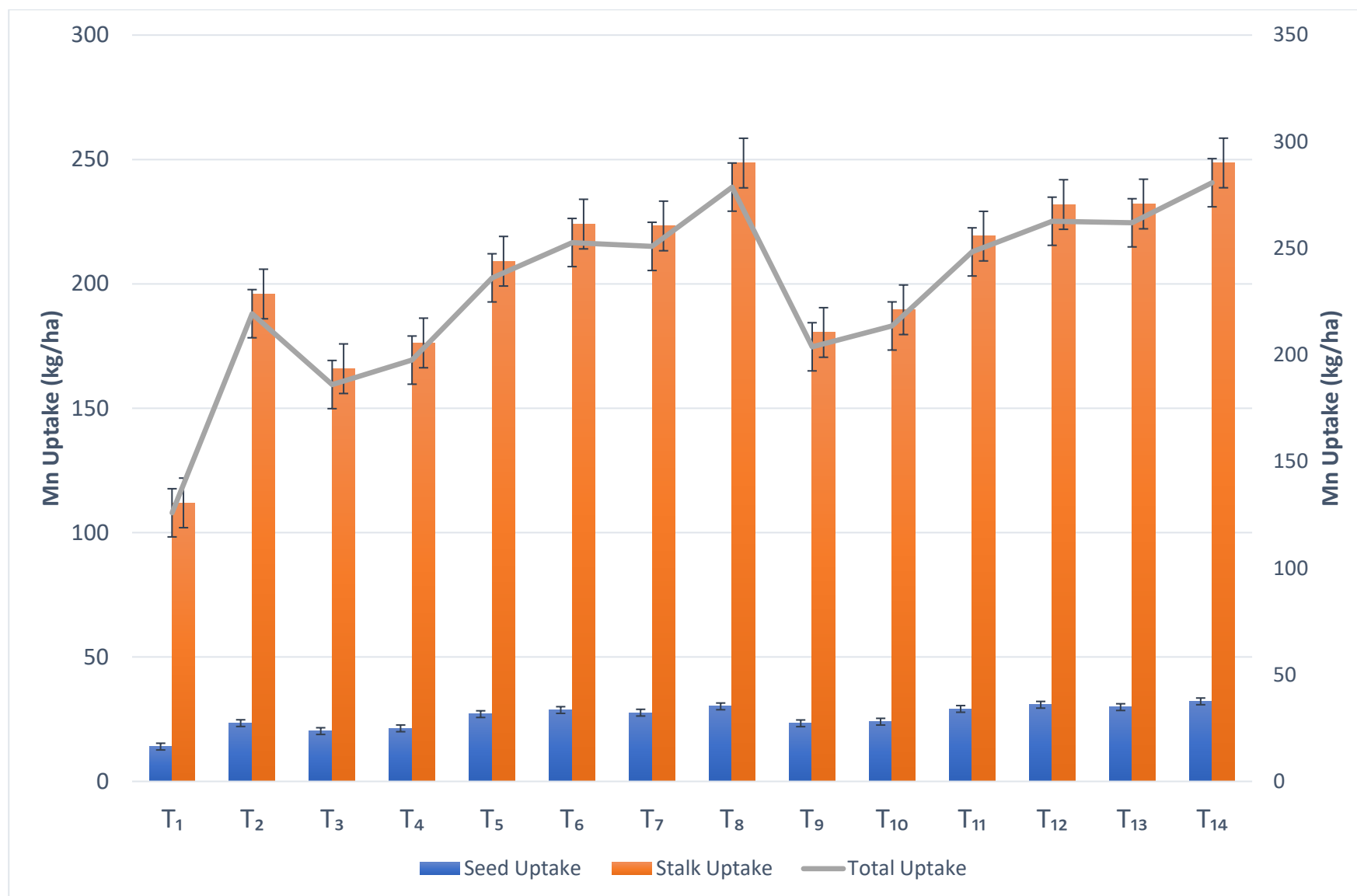


Fig. 9: Uptake of Manganese (g ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

4.6.9 Zinc uptake (g ha^{-1}) by sunflower.

Different levels of nano nitrogen, sulphur and zinc practice influenced on zinc uptake (g ha^{-1}) by sunflower after harvest of crop presented in Table 36.

Uptake of zinc by sunflower seeds significantly ($p < 0.05$) higher (77.46 g ha^{-1}) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm (T_{14}) followed by treatment 75% RDN + nU @ 2 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm (T_{13}) (72.16 g ha^{-1}) over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 53.99 g ha^{-1} . In contrast, significantly ($p < 0.05$) lower zinc uptake (31.75 g ha^{-1}) was recorded in absolute control.

In case of stalk, significantly ($p < 0.05$) higher zinc uptake was recorded in treatment receiving 75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm (T_{14}) (495.32 g ha^{-1}) which was on par with treatment T_8 (75% RDN + nU @ 4 ml/l + 50% ZnSO_4 + nS @ 100ppm + nZn @ 250ppm) (482.68 g ha^{-1}) over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 380.12 g ha^{-1} . In contrast, significantly ($p < 0.05$) lower zinc uptake (216.29 g ha^{-1}) was recorded in absolute control.

Total zinc uptake was recorded significantly ($p < 0.05$) higher with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO_4 + nS @ 200ppm + nZn @ 500ppm (T_{14}) (572.78 g ha^{-1}) over all the treatments, which was on par with treatment T_8 (75% RDN + nU @ 4 ml/l + 50% ZnSO_4 + nS @ 100ppm + nZn @ 250ppm) (551.77 g ha^{-1}) over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 434.11 g ha^{-1} . Whereas, lower total zinc uptake was recorded in untreated plot 248.05 g ha^{-1} .

The increase in zinc concentration in the seeds and stover of sunflower with the application of different levels of nano zinc as a foliar spray can be attributed to several key factors: Through foliar spray, nano zinc, in its highly soluble and easily accessible form, may be successfully absorbed by sunflower plants. This promotes better zinc absorption, leading in higher zinc concentrations in both the seeds and the stover (Taheri *et al.*, 2015). Traditional zinc fertilizers put to the soil might be leached or fixed in the soil, making them less accessible to plants. Nano zinc as a foliar spray reduces these losses since it is given directly to the plant leaves, lowering the

Table 36: Uptake of Zinc (g ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Zinc (g ha ⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	34.41	29.16	31.75	227.65	205.23	216.29	262.05	234.39	248.05
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	59.92	48.26	53.99	398.34	362.28	380.12	458.26	410.54	434.11
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	52.68	41.54	47.05	338.84	309.95	324.25	391.52	351.50	371.30
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	55.19	42.48	48.71	362.32	327.46	344.68	417.52	369.94	393.39
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	68.07	53.78	60.83	431.07	391.31	410.97	499.14	445.09	471.80
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	71.36	56.58	63.87	461.80	416.73	438.99	533.16	473.31	502.85
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	72.98	57.84	65.33	453.82	415.08	434.26	526.80	472.92	499.59
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	78.07	60.46	69.10	508.21	457.78	482.68	586.28	518.24	551.77
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	60.04	47.39	53.64	375.95	337.79	356.62	435.98	385.18	410.26
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	62.36	49.33	55.75	391.94	356.87	374.22	454.29	406.20	429.98
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	74.50	59.18	66.70	452.12	411.47	431.57	526.62	470.65	498.27
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	78.65	61.09	69.72	481.05	433.50	456.98	559.71	494.59	526.70
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	80.17	64.38	72.16	486.24	437.38	461.50	566.40	501.76	533.66
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	86.65	68.60	77.46	517.84	473.25	495.32	604.49	541.84	572.78
	S.Em ±	1.84	1.46	1.65	11.53	10.45	10.98	13.36	11.91	12.63
	CD @ 5%	5.35	4.24	4.78	33.50	30.38	31.92	38.85	34.62	36.71

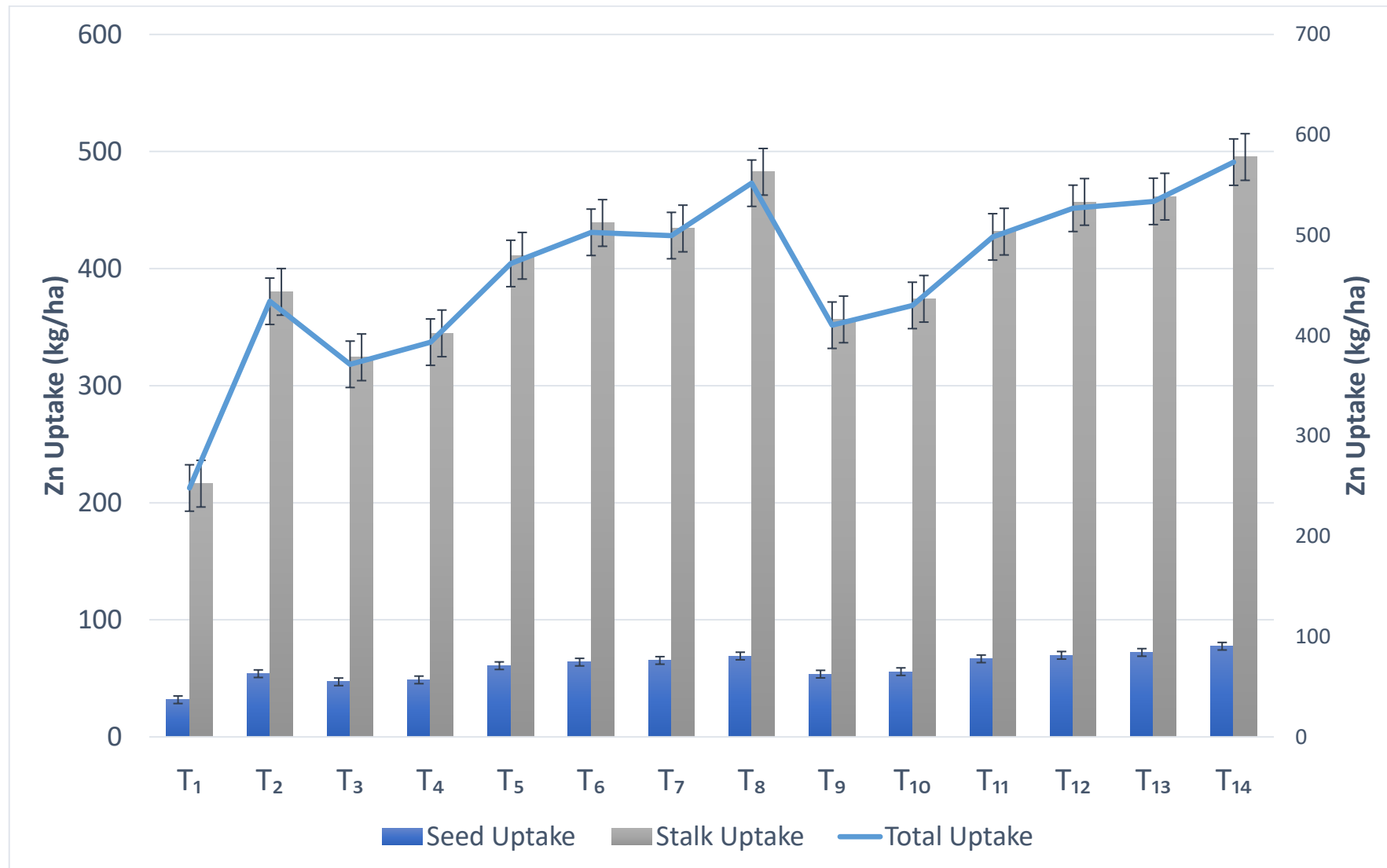


Fig. 10: Uptake of Zinc (g ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

danger of nutrient leaching or immobilization in the soil and encouraging greater zinc concentrations as given by Afshar *et al.* (2014)

Nano zinc foliar spraying provides highly accurate and targeted nutrient delivery. It reduces nutrient waste by delivering zinc straight to the plant's leaves, where it is easily absorbed and translocated (Chandana *et al.*, 2021). This accuracy helps to a more efficient zinc delivery, resulting in increased zinc concentrations in the seeds and stover. The absorption and assimilation kinetics of nano-based zinc formulations are frequently quicker as stated by Mohsen *et al.* (2016). Zinc build-up in the seeds and stover is accelerated by the plant's fast zinc absorption. Nano zinc foliar sprays have the ability to lessen the environmental effect of zinc fertilizer application. By directly targeting the plant, surplus zinc in the soil is reduced, lowering the danger of environmental contamination and assuring a more sustainable approach to zinc supplementation (Sarkar *et al.*, 2013). The use of varied quantities of nano zinc as a foliar spray provides for precise control over the zinc supply to the plant, ensuring that it satisfies the crop's individual demands at different stages of growth. As a result, zinc concentrations in harvested seeds and stover may be greater. Traditional zinc treatments can occasionally cause nutritional imbalances and plant stress (Mahajan *et al.*, 2013). When administered correctly, nano zinc can help minimize such stress by helping plants to efficiently use the mineral for growth and development, resulting in greater zinc concentrations in the crop as outlined by Azamal and Khawaja (2014) and Hafeez *et al.* (2015).

4.6.10 Copper uptake (g ha^{-1}) by sunflower.

Copper uptake (g ha^{-1}) influenced by different levels of nano nitrogen, sulphur and zinc practice on sunflower presented in Table 37.

Uptake of copper by sunflower significantly ($p < 0.05$) higher (14.64 and 60.70 g ha^{-1} in seeds and stalk, respectively) was recorded in treatment $75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$ (T_{14}) followed by treatment T_8 ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 50\% \text{ ZnSO}_4 + \text{nS @ } 100\text{ppm} + \text{nZn @ } 250\text{ppm}$) (13.95 and 58.15 g ha^{-1} in seeds and stalk, respectively) over treatment T_2 which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 11.13 and 46.32 g ha^{-1} in seeds and stalk, respectively. In contrast, significantly ($p < 0.05$) lower copper uptake (6.62 and 26.50 g ha^{-1} in seeds and stalk, respectively) was recorded in absolute control.

Table 37: Uptake of Copper (g ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Copper (kg ha ⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	7.00	6.25	6.62	27.38	25.64	26.50	34.38	31.89	33.12
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	11.72	10.55	11.13	47.55	45.10	46.32	59.27	55.65	57.44
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	9.99	8.99	9.48	40.39	38.45	39.41	50.38	47.44	48.90
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.69	9.40	10.04	43.24	40.63	41.93	53.94	50.03	51.97
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.14	12.07	12.60	51.43	48.64	50.02	64.57	60.71	62.63
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.79	12.49	13.14	55.39	52.13	53.75	69.19	64.62	66.89
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.61	12.37	12.99	53.50	50.98	52.23	67.11	63.35	65.21
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	14.74	13.18	13.95	59.98	56.34	58.15	74.72	69.52	72.10
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	11.24	10.33	10.78	44.59	41.78	43.17	55.83	52.10	53.95
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	11.66	10.48	11.06	46.61	44.34	45.47	58.27	54.82	56.53
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	13.94	12.46	13.19	54.58	51.75	53.16	68.52	64.21	66.35
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	14.63	13.07	13.84	58.28	54.72	56.49	72.91	67.79	70.33
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	14.57	13.06	13.80	58.02	54.48	56.24	72.59	67.54	70.04
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	15.59	13.73	14.64	62.20	59.22	60.70	77.79	72.94	75.34
	S.Em ±	0.35	0.31	0.33	1.38	1.30	1.34	1.72	1.61	1.67
	CD @ 5%	1.01	0.90	0.95	4.00	3.78	3.89	5.01	4.69	4.85

Table 38: Uptake of Boron (g ha⁻¹) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Boron (g ha⁻¹)										
Treatments	Details	Seed Uptake			Stalk Uptake			Total Uptake		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	96.79	94.68	95.41	49.40	45.51	47.44	146.20	140.18	142.85
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	162.16	153.86	157.99	86.00	80.59	83.27	248.16	234.45	241.26
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	139.11	132.38	135.73	73.65	67.15	70.37	212.76	199.53	206.09
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	147.42	135.25	141.27	79.53	70.94	75.18	226.95	206.18	216.44
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	182.00	166.36	174.11	93.80	83.81	88.74	275.80	250.17	262.85
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	189.13	171.90	180.42	101.49	91.04	96.20	290.62	262.95	276.62
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	191.59	178.08	184.78	101.04	91.77	96.36	292.63	269.85	281.14
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	206.37	187.54	196.84	114.49	101.63	107.98	320.86	289.17	304.82
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	152.09	139.17	145.57	85.41	76.27	80.78	237.50	215.45	226.35
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	156.79	148.56	152.65	89.34	81.34	85.30	246.13	229.91	237.95
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	188.96	171.55	180.15	102.02	91.03	96.46	290.99	262.58	276.61
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	195.73	182.93	189.28	110.70	98.64	104.59	306.44	281.58	293.87
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	199.93	186.19	193.00	111.41	98.87	105.05	311.34	285.06	298.05
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	212.68	196.35	204.43	118.28	108.45	113.31	330.96	304.79	317.75
	S.Em ±	4.73	4.40	4.57	2.59	2.33	2.46	7.32	6.74	7.02
	CD @ 5%	13.76	12.80	13.28	7.52	6.79	7.15	21.28	19.59	20.42



Fig. 11: Uptake of Copper (g ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

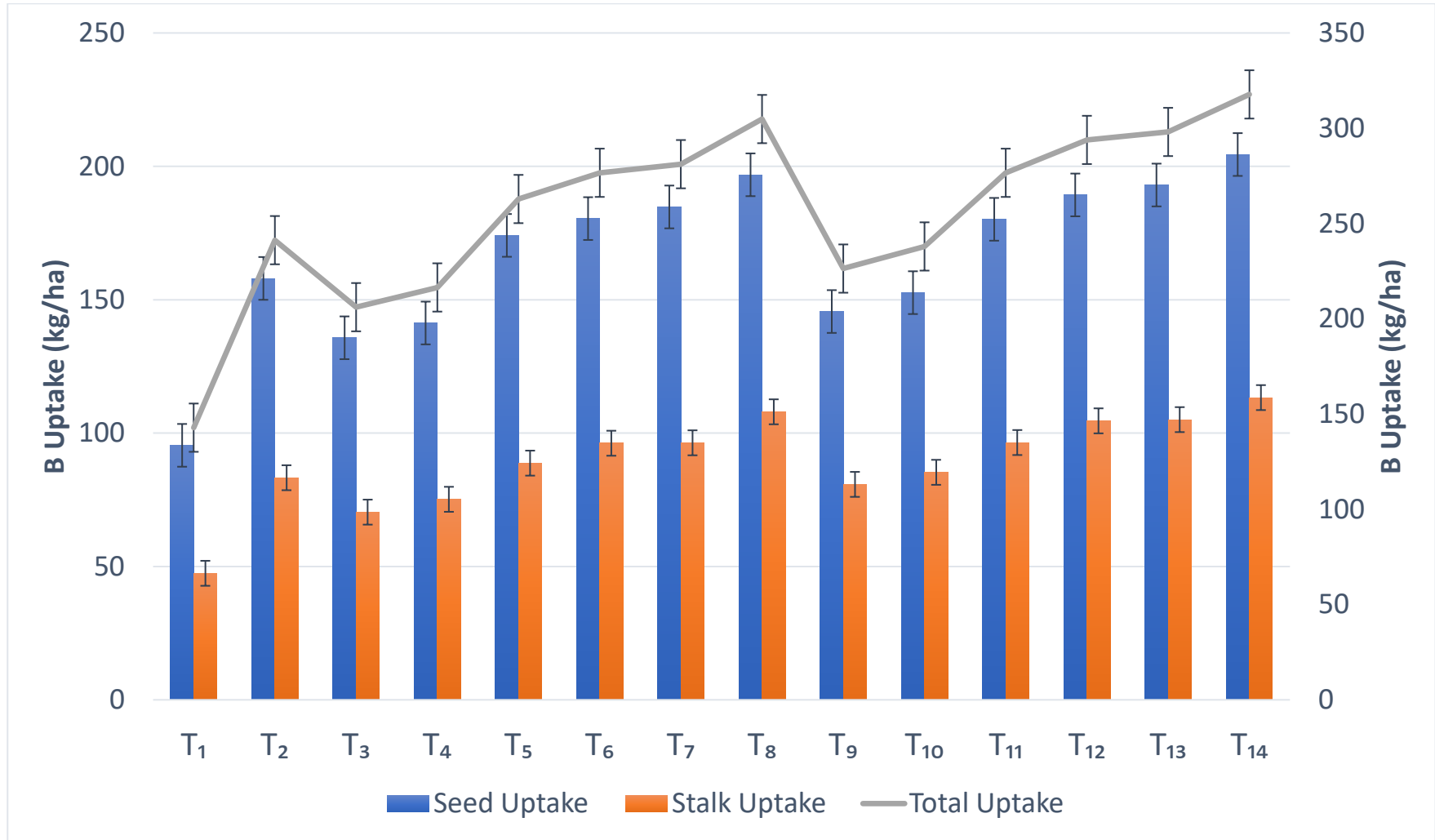


Fig. 12: Uptake of Boron (g ha^{-1}) by sunflower as influenced by different levels of Nano Nitrogen, Sulphur and Zinc application

Total copper uptake was recorded significantly ($p < 0.05$) higher with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) (75.34 g ha⁻¹) over all the treatments, which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (72.10 g ha⁻¹) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 57.44 g ha⁻¹. Whereas, lower total copper uptake was recorded in untreated plot 33.12 g ha⁻¹.

4.6.11 Boron uptake (g ha⁻¹) by sunflower.

Different levels of nano nitrogen, sulphur and zinc practice influenced on boron uptake (g ha⁻¹) by sunflower after harvest of crop presented in Table 38.

Significantly ($p < 0.05$) higher boron uptake by seed (204.43 kg ha⁻¹) and stalk (113.31 kg ha⁻¹) was recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) followed by treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (206.37 and 107.98 kg ha⁻¹ in seeds and stalk, respectively) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 157.99 and 83.27 kg ha⁻¹ in seeds and stalk, respectively. In contrast, significantly ($p < 0.05$) lower boron uptake (95.41 and 47.44 kg ha⁻¹ in seeds and stalk, respectively) was recorded in absolute control.

Total boron uptake (317.75 g ha⁻¹) was recorded significantly ($p < 0.05$) higher with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) over all the treatments, which was on par with treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (304.82 g ha⁻¹) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 241.26 g ha⁻¹. Whereas, lower total boron uptake was recorded in untreated plot 142.85 g ha⁻¹.

4.6.12 Nutrients use efficiency (kg kg⁻¹) by sunflower as influenced by different levels of nano nitrogen, Sulphur and Zinc application.

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 39.

Results showed that with the application of 25% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₀) recorded higher Nitrogen (N) use efficiency (kg kg⁻¹) by sunflower *i.e.*, 72.01 kg kg⁻¹ that was on par with treatment T₉ (25% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) which recorded 65.82 kg kg⁻¹ when compare to treatment T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)) recorded 20.72 kg kg⁻¹.

In case of Phosphorus (P) and Potassium (K) use efficiency , treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded higher nutrient use efficiency (26.47 and 35.29 kg kg⁻¹ Phosphorus and Potassium use efficiency, respectively) that was on par with treatment which had 75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm (T₈) recorded (24.87 and 33.16 kg kg⁻¹ Phosphorus and Potassium use efficiency, respectively) over treatment T₂ (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 increase in Nitrogen (N), Phosphorus (P), and Potassium (K) nutrient use efficiency with the application of different levels of nitrogen and zinc sulphate to soil, as well as nano nutrients (nano nitrogen, nano sulphur, and nano zinc) as foliar spray to sunflower, can be attributed to Adjusting nitrogen levels in the soil can enhance nutrient availability for sunflower plants. Adequate nitrogen promotes better absorption and utilization of phosphorus and potassium. Zinc sulphate application to the soil helps in optimizing zinc availability. Zinc is crucial for various physiological processes, including nutrient uptake and enzyme activation as indicated by WA Al-juthery *et al.* (2019) and Al-Uthery *et al.* (2019)

Properly calibrated levels of nitrogen, phosphorus, and potassium ensure a balanced nutrient ratio in the soil, promoting optimal plant growth and development. Nano nutrients as foliar sprays can provide a precise and easily absorbable form of nutrients, helping to maintain an appropriate balance (Sarkar *et al.* 2013). Nano-sized particles in foliar sprays can penetrate plant tissues more effectively, leading to increased nutrient uptake efficiency. Nano-sized nutrients can overcome certain soil conditions that may limit the availability and uptake of traditional forms of nutrients as noted by Al-Uthery *et al.* (2019). Nitrogen application can influence soil structure positively, promoting aeration and water infiltration. This can enhance microbial activity, which in turn aids in nutrient cycling and availability. Zinc sulfate can also contribute to improved microbial activity, supporting nutrient mineralization and release as recorded by Badran and Savin (2017).

Adequate nitrogen levels stimulate enzymatic activity in plants, which is crucial for nutrient metabolism. This can positively impact the utilization of phosphorus and potassium. Nano-sized nutrients may directly interact with enzymes, potentially enhancing their activity and improving nutrient assimilation as stated by Sumathi and Koteswara Rao (2007)

Zinc sulphate application addresses zinc deficiencies, which can be a limiting factor for nutrient uptake in plants. Nano-sized nutrients in foliar sprays offer a quick and targeted solution to nutrient deficiencies, ensuring that the plant has access to essential elements when needed as outlined by Burmana *et al.* (2013) and Jhanzab *et al.* (2015). Foliar application of nano-sized nutrients allows for direct absorption by plant leaves, bypassing potential soil-related limitations. This can lead to more efficient nutrient utilization by sunflower plants as mentioned by Jhanzab *et al.* (2015). Nano-sized nutrients may have reduced environmental impact compared to conventional forms, as they can potentially be more targeted in their action, minimizing runoff and leaching. (Tarafdar *et al.*, 2012a).

4.7 Effect of different levels of nano nitrogen, sulphur and zinc on growth parameters of sunflower

4.7.1 Plant height (cm) of sunflower.

Plant height of sunflower at 30, 60 days after sowing (DAS) and at harvest as influenced by different levels of nano nitrogen, sulphur and zinc practice is presented in Table 40.

At 30 DAS, the plant height was recorded significant ($p < 0.05$) among different levels of nano nitrogen, sulphur and zinc practice. Among all the treatments, higher plant height (28.89 cm) was recorded with application of T_8 (75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @ 250ppm) when compare to treatment T_2 (24.88 cm) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Whereas, lower plant height (19.34 cm) was recorded in absolute control (T_1).

Plant height at 60 DAS was significantly ($p < 0.05$) influenced by different levels of nano nitrogen, sulphur and zinc practice. Significantly ($p < 0.05$) higher plant height (207.14 cm) was recorded with application of 75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @ 500ppm (T_{14}) which was found to be on par with application of treatment T_8 (75% RDN + nU

Table 40. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on plant height (cm) at 30DAS, 60DAS and at harvest stages of sunflower

Plant height (cm) of Sunflower										
Treatments	Details	30DAS			60 DAS			At harvest		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	19.84	18.85	19.34	140.13	135.92	138.02	143.63	139.32	141.48
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	25.52	24.24	24.88	180.25	174.84	177.55	184.76	179.21	181.98
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.86	21.72	22.29	161.46	156.62	159.04	165.50	160.53	163.02
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.97	22.09	22.53	162.24	157.37	159.81	166.30	161.31	163.80
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	26.92	25.57	26.25	190.14	184.43	187.29	194.89	189.05	191.97
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	27.89	26.50	27.19	196.99	191.08	194.03	201.91	195.86	198.89
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	28.31	26.89	27.60	200.52	194.51	197.51	205.53	199.37	202.45
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	29.63	28.15	28.89	206.10	199.92	203.01	210.25	204.92	207.58
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	22.9	21.76	22.33	161.74	156.89	159.32	165.79	160.81	163.30
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	23.64	22.46	23.05	166.97	161.96	164.47	171.15	166.01	168.58
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	27.15	25.79	26.47	191.76	186.01	188.89	196.56	190.66	193.61
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	28.05	26.65	27.35	198.12	192.18	195.15	203.07	196.98	200.03
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	28.39	26.97	27.68	202.96	193.96	198.46	207.95	198.81	203.38
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	29.18	27.72	28.45	211.28	203.00	207.14	216.51	208.08	212.29
	S.Em ±	0.72	0.68	0.70	5.07	4.91	4.99	5.20	5.03	5.11
	CD @ 5%	2.08	1.98	2.03	14.74	14.27	14.50	15.10	14.63	14.87

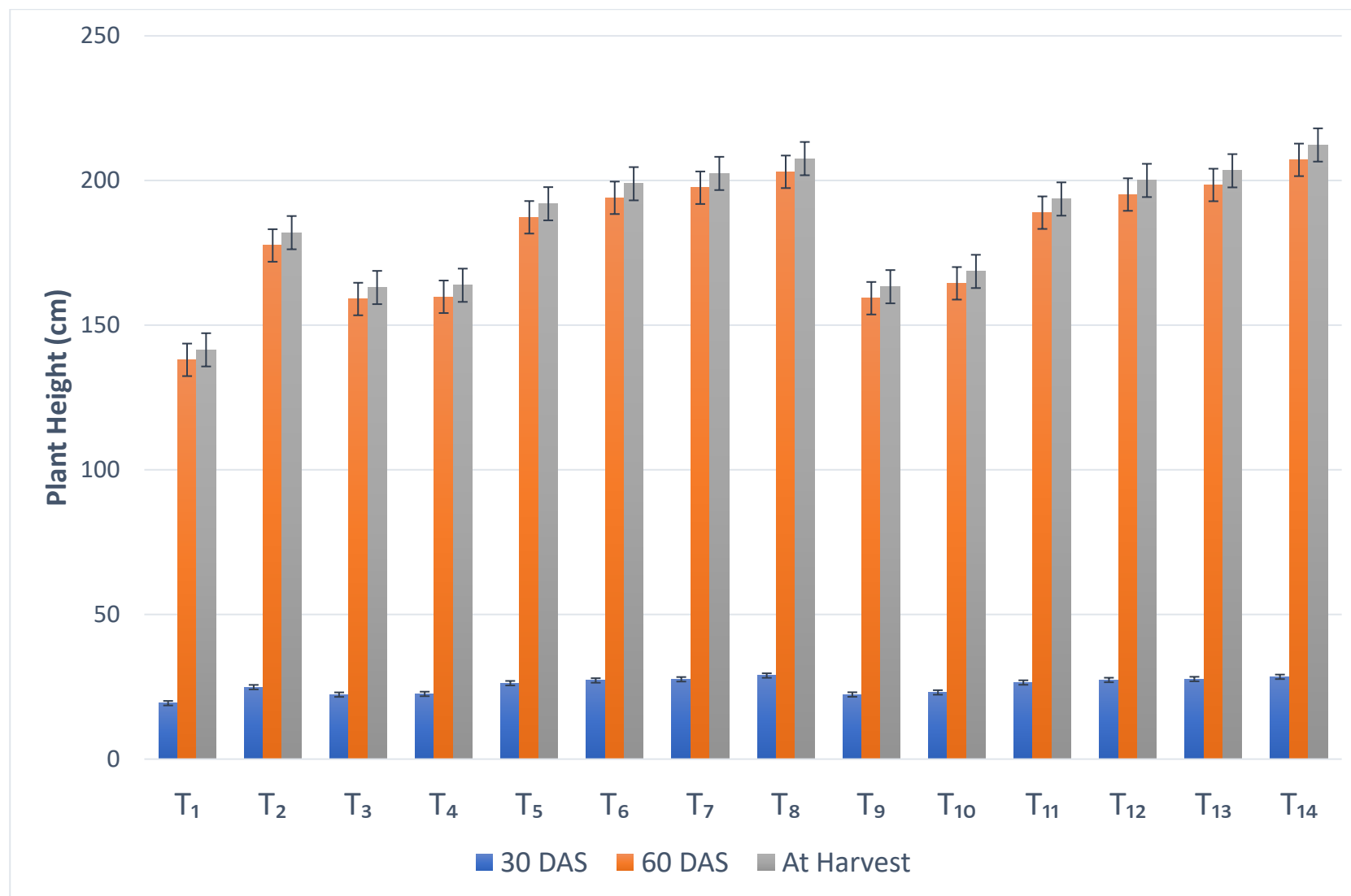


Fig. 13: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on plant height (cm) at 30DAS, 60DAS and at harvest stages of sunflower

@ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (203.01 cm) over treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 184.76 cm. However, the lower plant height (143.63 cm) was recorded in absolute control.

At harvest, plant height was significantly ($p < 0.05$) influenced by different levels of nano nitrogen, sulphur and zinc practice. Higher plant height (212.29 cm) was recorded with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @500ppm (T₁₄) and was found on par with application of treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (207.58 cm) when compare to treatment T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded 181.98 cm. However, the lower plant height (141.48 cm) was recorded in absolute control.

4.7.2 Number of green leaves (plant⁻¹) of sunflower.

The data on number of green leaves per plant of sunflower influenced by different levels of nano nitrogen, sulphur and zinc practice at 30 DAS and 60 DAS is presented in Table 41.

At 30 DAS, green leaves per plant were recorded and showed significant ($p < 0.05$) among different levels of nano nitrogen, sulphur and zinc practice. Among all the treatments, more green leaves (14.94 plant⁻¹) were recorded with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @500ppm (T₁₄) when compare to treatment T₂ (14.72 plant⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Whereas, less green leaves (10.01 plant⁻¹) were recorded in absolute control (T₁).

Green leaves per plant at 60 DAS was significantly ($p < 0.05$) influenced by different levels of nano nitrogen, sulphur and zinc practice. Significantly ($p < 0.05$) more green leaves (30.24 plant⁻¹) were recorded with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @500ppm (T₁₄) which was found to be on par with application of treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (29.78 plant⁻¹) over treatment T₂ (26.05 plant⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). However, the lower number of green leaves (20.25 plant⁻¹) was recorded in absolute control.

4.7.3 Days for first flowering, days for 50 per cent flowering and days for physiological maturity of sunflower

Data pertaining to Days for first flowering, days for 50 per cent flowering and days for physiological maturity of sunflower are presented in the Table 42.

different levels of nano nitrogen, sulphur and zinc nutrient application did not influenced the Days for first flowering, days for 50 per cent flowering and days for physiological maturity of sunflower significantly ($p < 0.05$). However, with application of treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) recorded late Days for first flowering, days for 50 per cent flowering and days for physiological maturity of sunflower (56.02, 62.24 and 93.37 days respectively) compared to RDF alone (69.67 days and 89.67 days respectively) compared to absolute control (T₁) recorded 53.75, 60.02 and 89.58 days, respectively.

Nano-sized nitrogen particles can be absorbed more readily by the plant through the leaves. This improved nutrient uptake promotes better overall growth, as nitrogen is an essential element for plant development as given by Sharma *et al.* (2022). Nano nitrogen can be transported more efficiently within the plant, leading to a more uniform distribution of nutrients throughout the sunflower as stated by Shinde *et al.* (2015). This supports the development of both leaves and stems. The availability of nano nitrogen can enhance the photosynthetic capacity of the plant. This results in greater energy production and, consequently, more extensive leaf growth as outlined by Babita *et al.* (2020).

Nitrogen is a key component of chlorophyll, which is vital for photosynthesis. With increased nitrogen availability, sunflowers can produce more chlorophyll, leading to healthier and more numerous leaves as mentioned by Nissanaka (2014). Nitrogen is essential for protein synthesis in plants. Higher nitrogen levels, especially in a nano-sized form, can stimulate increased protein production, contributing to the overall dry matter production of the plant as recorded by Al Jabri *et al.* (2020). Nano-sized nutrients can help the plant better cope with environmental stressors like drought, heat, or disease. When plants are less stressed, they can allocate more energy and resources to growth as mentioned by Rasool *et al.* (2013). Nano nitrogen may affect the regulation of growth hormones, such as auxins and cytokinins. These hormones play a crucial role in controlling plant height and overall development. Traditional nitrogen fertilizers are often susceptible to leaching, volatilization, and denitrification, which can result in nitrogen loss as given

Table 41. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on number of green leaves at 30DAS and 60DAS stages of sunflower

Number of green leaves of sunflower							
Treatments	Details	30DAS			60DAS		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	10.26	9.75	10.01	20.66	19.84	20.25
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	13.20	12.54	12.87	26.58	25.52	26.05
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	11.82	11.23	11.53	23.81	22.86	23.33
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	11.88	11.29	11.58	23.92	22.97	23.45
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	13.92	13.23	13.58	28.04	26.92	27.48
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	14.43	13.70	14.07	29.05	27.89	28.47
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	14.68	13.95	14.32	29.57	28.39	28.98
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	15.09	14.34	14.72	30.39	29.18	29.78
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	11.84	11.25	11.55	23.85	22.90	23.37
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	12.23	11.62	11.92	24.62	23.64	24.13
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	14.04	13.34	13.69	28.28	27.15	27.71
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	14.51	13.78	14.15	29.22	28.05	28.63
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	14.64	13.91	14.28	29.49	28.31	28.90
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	15.33	14.56	14.94	30.86	29.63	30.24
	S.Em ±	0.37	0.35	0.36	0.75	0.72	0.73
	CD @ 5%	1.08	1.02	1.05	2.17	2.08	2.13

Table 42. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Plant growth parameters of Sunflower

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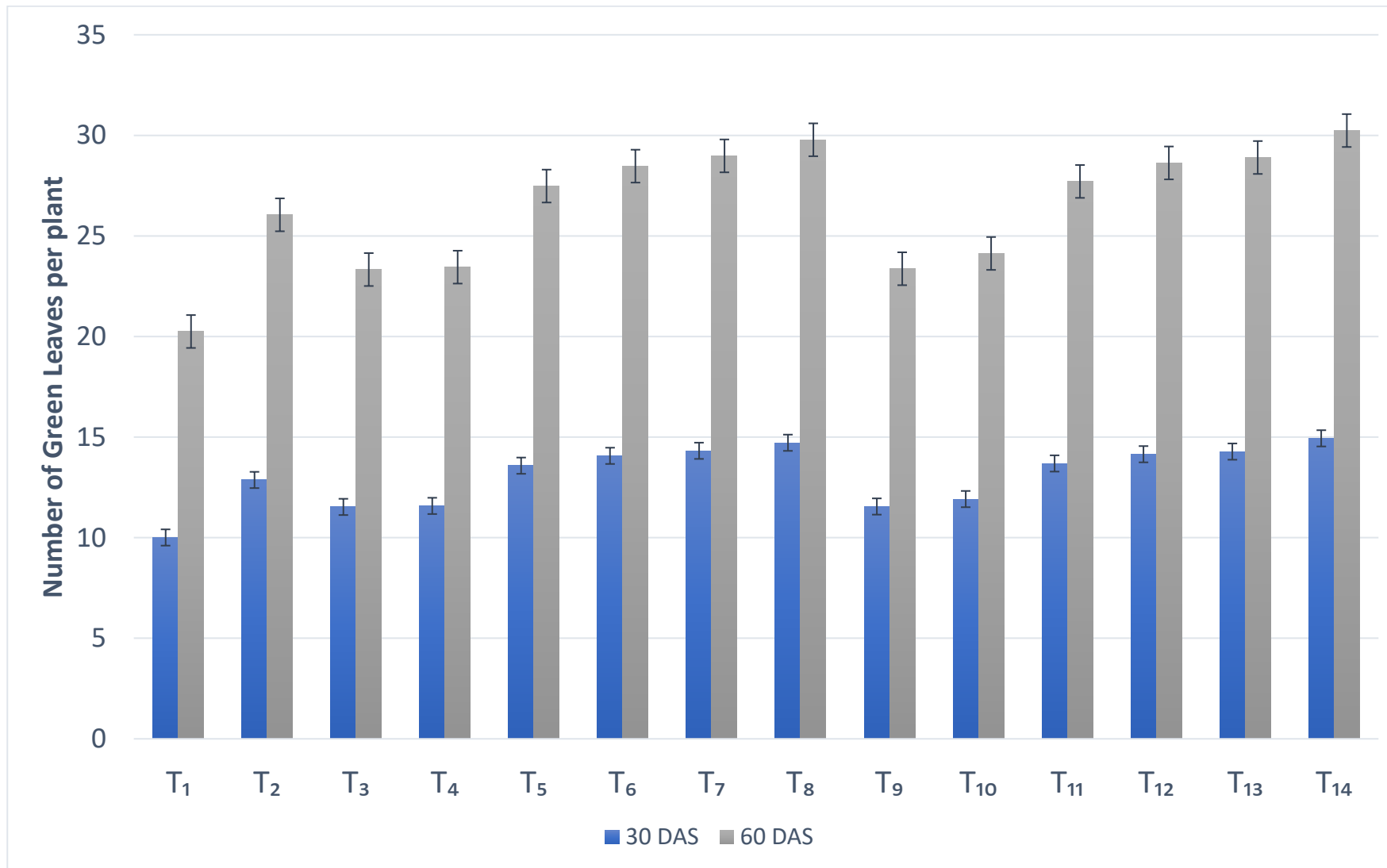
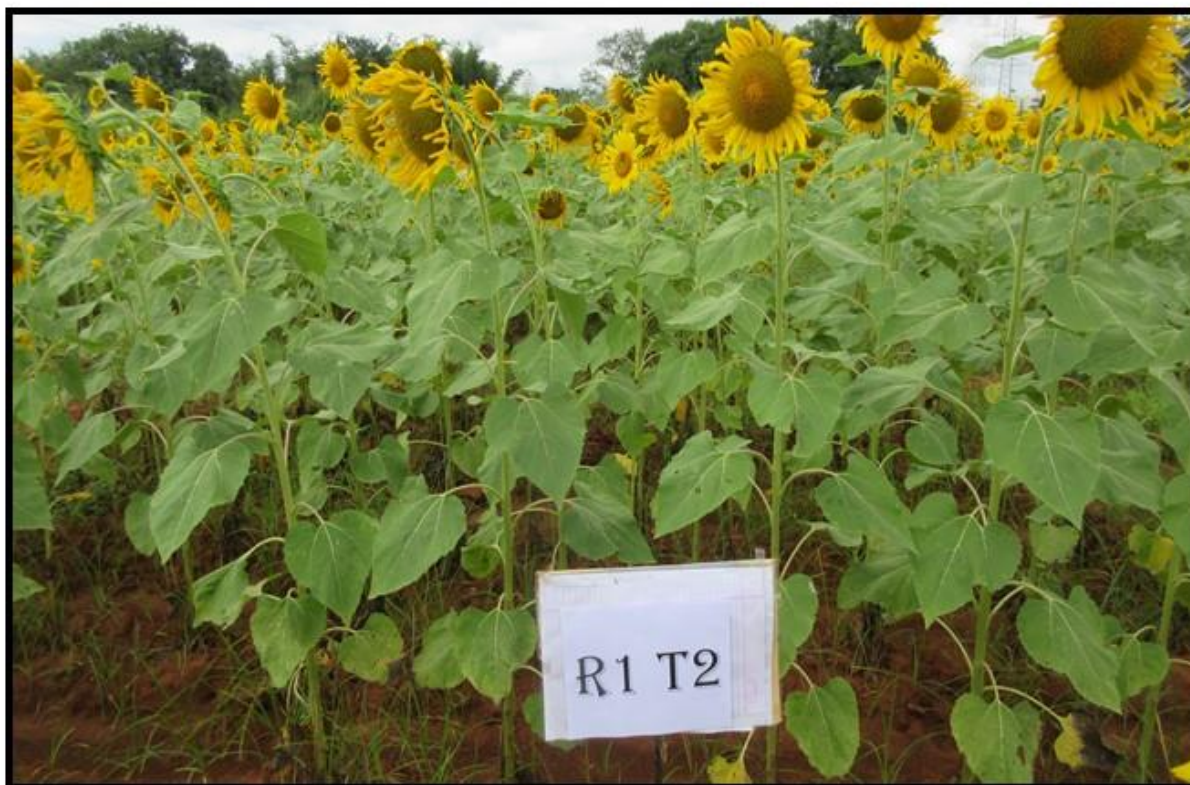


Fig. 14: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on number of green leaves at 30DAS and 60DAS stages of sunflower



T₂ - Package of practice (FYM + Bio fertilizers + NPK + Zn + B)



T₁₄ - 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm

Plate 3: Visual comparison of different treatments at full flowering stage

by Kaleri *et al.* (2019). Nano nitrogen, when applied as a foliar spray, reduces the risk of such losses, ensuring a steady supply of nitrogen for plant growth as outlined by Kumar *et al.* (2013). Improved nitrogen availability can indirectly stimulate root growth. Healthy roots can absorb more water and nutrients, leading to better overall plant growth as specified by Rathnayaka *et al.* (2018). Nano-sized particles may interact positively with other nutrients, enhancing their effectiveness. This synergy can further boost plant growth parameters as marked by El-kady *et al.* (2010)

Using nano-sized nutrients may allow for lower application rates of nitrogen, which can reduce the environmental impact and potential runoff into water bodies as given by Dambale *et al.* (2018). It's important to note that the effectiveness of nano nitrogen as a foliar spray may depend on various factors, including the specific formulation of the product, application timing, and the local environmental conditions as stated by Abdel-Salam *et al.* (2018). Additionally, it's crucial to follow recommended application rates and guidelines to avoid overuse, which can lead to nutrient imbalances or environmental issues as mentioned by Oad *et al.* (2018).

4.8 Effect of different levels of nano nitrogen, sulphur and zinc on yield parameters of sunflower

Data of number of filled seeds per head, number of unfilled seeds per head and total number of seeds per head are presented in Table 43 whereas percent chaffiness, seed test weight (100 seed weight) and Dry matter production (g plant⁻¹) are presented in Table 44

4.8.1 Number of filled seeds per head of sunflower

Data of number of filled seeds per head as influenced by different treatments are presented in Table 43. Maximum number of filled seeds per head was recorded with the application 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @500ppm (T₁₄) (942) which was found at par with the application T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (931) and found significantly ($p < 0.05$) superior over T₂ (26.05 plant⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B).

4.8.2 Number of unfilled seeds per head of sunflower

Data of number of unfilled seeds per head as influenced by various treatments are presented in Table 43. maximum number of unfilled seeds per head was recorded with the application of T₂

Table 43. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Plant yield parameters of Sunflower

Plant yield parameters of Sunflower										
Treatments	Details	Filled seeds per head			chaffy seeds per head			Total seeds per head		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	453	442	448	97	101	99	550	543	547
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	718	701	709	112	105	109	830	806	818
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	593	579	586	65	71	68	659	650	654
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	634	619	626	72	65	69	706	684	695
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	766	747	757	81	75	78	847	822	835
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	816	796	806	80	72	76	896	868	882
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	872	851	861	82	85	84	954	936	945
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	931	909	920	84	89	87	1015	998	1006
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	605	590	598	56	51	54	661	641	651
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	649	633	641	58	55	57	707	688	698
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	789	770	779	68	64	66	858	834	845
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	836	816	826	73	72	73	910	888	898
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	883	862	872	70	65	68	953	927	940
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	955	932	943	75	69	72	1030	1001	1015
	S.Em ±	20.44	19.95	20.19	2.19	2.12	2.15	22.55	22.06	22.31
	CD @ 5%	59.43	57.99	58.71	6.37	6.16	6.26	65.54	64.15	64.85

Table 44. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Plant yield parameters of Sunflower

Plant yield parameters of Sunflower										
Treatments	Details	Percent Chaffiness			100 Seeds weight (g)			Total dry matter production per plant (g)		
		2021	2022	Pooled	2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	17.63	18.60	18.11	3.09	3.15	3.12	69.56	66.85	68.21
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	13.50	13.03	13.27	3.59	3.55	3.57	118.88	114.74	116.81
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	9.89	10.93	10.40	3.18	3.20	3.19	100.51	97.74	99.12
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.19	9.51	9.86	3.26	3.24	3.25	106.78	102.11	104.44
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	9.52	9.12	9.34	3.62	3.60	3.61	128.09	123.91	126.00
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	8.94	8.29	8.62	3.69	3.71	3.70	136.10	131.01	133.55
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	8.59	9.08	8.84	3.95	3.90	3.93	134.73	131.15	132.94
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	8.24	8.92	8.60	3.99	3.98	3.99	148.75	142.36	145.56
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	8.47	7.95	8.22	3.67	3.66	3.67	108.95	104.83	106.89
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	8.23	7.99	8.10	3.79	3.85	3.82	113.17	109.74	111.45
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	7.97	7.67	7.81	3.71	3.66	3.69	131.96	127.01	129.49
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	8.07	8.11	8.07	3.88	3.81	3.85	139.22	133.39	136.31
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	7.34	7.01	7.18	4.01	4.05	4.03	141.57	136.07	138.82
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	7.28	6.89	7.09	4.13	4.07	4.10	150.61	145.42	148.02
	S.Em ±	0.30	0.29	0.29	0.01	0.01	0.01	3.38	3.26	3.32
	CD @ 5%	0.88	0.85	0.87	NS	NS	NS	9.82	9.48	9.65

(109) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) followed by the control treatment (T₁) recorded number of unfilled seeds per head (99) which was found significantly ($p<0.05$) superior over rest of the treatments.

4.8.3 Per cent Chaffiness of sunflower seeds

Percent Chaffiness was significantly ($p<0.05$) influenced by foliar application of different levels of nano nitrogen, sulphur and zinc practice. The data are presented in the Table 44. Control treatment (T₁) recorded higher Per cent Chaffiness (18.11 %) followed by T₂ which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) recorded (13.27 %). However, significantly ($p<0.05$) least Percent Chaffiness (7.09 %) was recorded with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄).

4.8.4 Test weight (g) of sunflower

Data on test weight (g) as influenced by various treatments is presented in Table 44. different levels of nano nitrogen, sulphur and zinc practice did not influence the test weight of sunflower seeds. Numerically, highest weight of 100 seeds (g) was observed with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) (4.10 g) over T₂ (3.57 g) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Lowest test weight (3.12 g) was observed with control treatment (T₁).

4.8.5 Dry matter production (g plant⁻¹) of sunflower.

Dry matter production (g plant⁻¹) of sunflower influenced by different levels of nano nitrogen, sulphur and zinc practice at harvest is presented in Table 44.

Total dry matter at harvest was significantly ($p<0.05$) influenced by different levels of nano nitrogen, sulphur and zinc practice. Significantly ($p<0.05$) higher total dry matter (148.02 g plant⁻¹) was recorded with application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄), which was found to be on par with application of treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (145.56 g plant⁻¹) and treatment 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₃) (138.82 g plant⁻¹) over treatment T₂ had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). which recorded 116.81 g plant⁻¹. The lower total dry matter (68.21 g plant⁻¹) was recorded in absolute control.

4.8.6 Seed yield (kg ha⁻¹) of sunflower

Data on seed yield (kg ha⁻¹) as influenced by different levels of nano nitrogen, sulphur and zinc practice are presented in Table 45.

The seed yield of sunflower differed significantly ($p < 0.05$) due to the different treatments. The maximum seed yield (2510.91 kg ha⁻¹) was produced with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) which was found at par with the application of T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (2431.16 kg ha⁻¹) followed by 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₃) (2368.84 kg ha⁻¹) and significantly ($p < 0.05$) superior over T₂ (1964.36 kg ha⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Lowest seed yield of sunflower (1187.48 kg ha⁻¹) was observed with absolute control treatment (T₁).

4.8.7 Stalk yield (kg ha⁻¹) of sunflower

Data on stalk yield kg ha⁻¹ as influenced by different treatments are presented in Table 45. The stalk yield was significantly ($p < 0.05$) influenced by different levels of nano nitrogen, sulphur and zinc practice. The maximum stalk yield (4537.47 kg ha⁻¹) was produced with the application of 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₄) which was found at par with the application of T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) (4500.06 kg ha⁻¹) and significantly ($p < 0.05$) superior over T₂ (3598.22 kg ha⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Lowest stalk yield of sunflower (2060.45kg ha⁻¹) was observed with absolute control treatment (T₁).

The use of nano-sized nutrients as a foliar spray, such as nano nitrogen, nano sulphur, and nano zinc, can improve seed filling, seed production, and stalk yield in sunflower plants. Nano-sized nutrients may be taken more easily by the plant through the leaves. This enhanced nutrient absorption has a direct impact on seed filling and overall plant development as given by Sumai *et al.* (2022). The use of nano nitrogen, nano sulphur, and nano zinc together can have a synergistic impact. These nutrients collaborate to promote many elements of plant growth, such as seed and stem production. Photosynthesis requires the elements nitrogen, sulphur, and zinc (Muhammad and Maqbool, 2015). They are critical components of chlorophyll, enzymes, and co-factors that are necessary for energy production. Enhanced photosynthesis results in more energy available for

Table 45. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Seed and Stalk yield of sunflower

Seed and Stalk yield of sunflower							
Treatments	Details	Seed Yield (kg ha ⁻¹)			Stalk Yield (kg ha ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	1204.67	1170.28	1187.48	2107.66	2013.14	2060.40
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	2003.26	1925.45	1964.36	3657.89	3538.56	3598.22
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1703.13	1660.38	1681.76	3082.86	2993.86	3038.36
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1791.44	1705.44	1748.44	3293.23	3156.79	3225.01
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2194.38	2133.54	2163.96	3904.97	3766.90	3835.93
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2290.86	2216.46	2253.66	4190.17	4022.02	4106.10
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2306.65	2251.67	2279.16	4108.85	3993.57	4051.21
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	2486.98	2375.35	2431.16	4596.32	4403.80	4500.06
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1828.19	1780.83	1804.51	3359.97	3211.17	3285.57
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1892.42	1832.70	1862.56	3496.61	3392.98	3444.80
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	2252.77	2149.77	2201.27	4031.00	3898.47	3964.73
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	2347.20	2250.72	2298.96	4282.49	4101.07	4191.78
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	2408.20	2329.48	2368.84	4333.27	4150.05	4241.66
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	2568.22	2453.60	2510.91	4603.86	4471.07	4537.47
	S.Em ±	54.42	53.72	54.07	99.36	97.70	98.53
	CD @ 5%	158.20	156.15	157.17	288.83	284.01	286.41

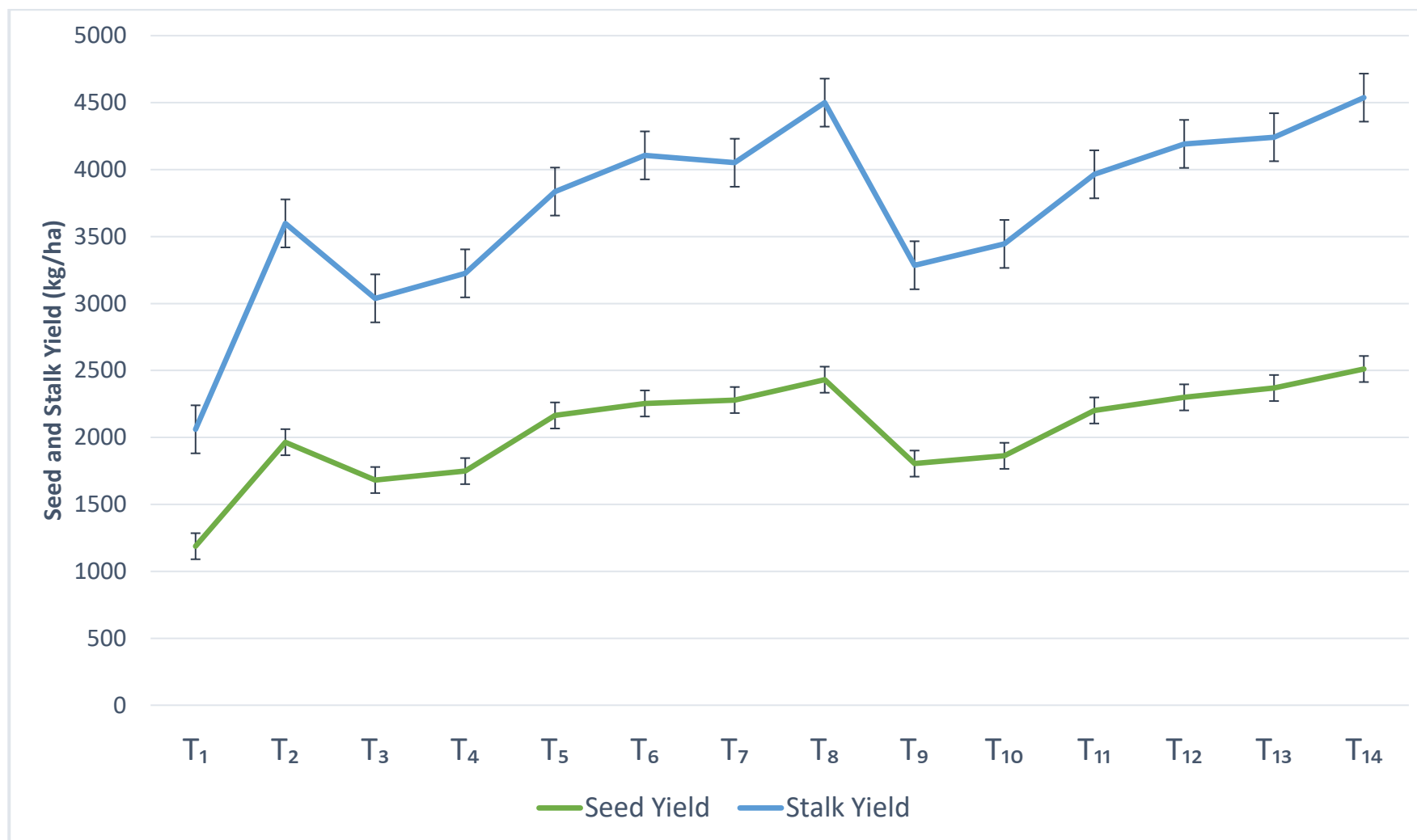


Fig. 15: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Seed and Stalk yield of sunflower

seed filling and overall plant growth as mentioned by Neogi and Das (2022), Sarvari *et al.* (2019) and Tiwari *et al.* (2021)

Sunflower plants require a diverse mix of nutrients. The use of nano nutrients aids in the maintenance of an optimum nutritional balance, reducing deficits that might impede seed and stalk growth as recorded by Jadav *et al.* (2015). Nitrogen and sulphur are essential for plant protein synthesis. higher quantities of these minerals can result in higher protein synthesis in sunflowers, which is necessary for seed formation as outlined by Kumar *et al.* (2022). Specific enzymes involved in nutrition digestion, transport, and metabolism can be activated or enhanced by nano-sized nutrients. This can boost the plant's capacity to properly absorb available nutrients as given by Umbarkar *et al.* (2017), Jadav *et al.* (2015) and Dambale *et al.* (2018)

Root health is critical for nutrient and water absorption. The use of nano nutrients can indirectly stimulate root health and growth, resulting in increased nutrient absorption and overall plant vigor as seen by Tiwari *et al.* (2021). Adequate nutritional levels, particularly micronutrients like zinc, can help sunflowers deal with environmental stresses like drought, heat, or nutrient imbalances. With less stress, the plant may devote more resources to seed and stalk development as stated by Dambale *et al.* (2018). Adequate nutrition availability can promote blooming and pollen viability, which is required for effective pollination and seed set. When administered as a foliar spray, nano-sized nutrients are less prone to leaching or runoff than typical soil-applied fertilizers as mentioned by Kiran and Samal (2021). This helps to guarantee that the plant receives a steady supply of nutrients. Foliar application allows for more uniform and accurate nutrient delivery to different plant sections, which might result in balanced seed and stalk growth. Nano-sized nutrients are more mobile within the plant, allowing for more efficient translocation to developing seeds and stalks as outlined by Hegab *et al.* (2018), Neogi and Das (2022) and Sumai *et al.* (2022)

It's important to note that the effectiveness of these nano-sized nutrients can depend on factors such as the specific product formulation, application timing, and the local soil and environmental conditions as noted by Yogendra *et al.* (2020). Careful monitoring and adherence to recommended application rates and guidelines are essential to maximize benefits and prevent potential nutrient imbalances as given by Hegab *et al.* (2018,) Oad *et al.* (2018), Vaghani *et al.* (2018) and Kaleri *et al.* (2019).

4.9 Effect of different levels of nano nitrogen, sulphur and zinc on quality parameters of sunflower

4.9.1 Crude protein (%) content in sunflower seeds.

Result obtained due to application of different levels of nano nitrogen, sulphur and zinc practice in terms of crude protein (%) in sunflower seeds were recorded and are represented in Table 46.

With the application of foliar spray of different levels of nano nitrogen, sulphur and zinc had a significant ($p < 0.05$) impact on crude protein content of sunflower seeds. Among the treatments, 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) shown higher crude protein *i.e.*, 23.03 per cent over treatment T₂ (20.38 %) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B) followed by treatment T₆ (50% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (22.81 %) and then by treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (22.69 %). The minimum crude protein (9.50%) was recorded in absolute control.

4.9.2 Oil content (%) in sunflower seeds.

Different levels of nano nitrogen, sulphur and zinc practice had influenced significantly ($p < 0.05$) on oil content (%) of sunflower seeds presented in Table 46.

Higher oil content (%) in sunflower seeds recorded in treatment 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) *i.e.*, 42.61 % followed by 75% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₃) (42.20 %) and treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (41.97 %) over treatment T₂ (37.69%) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). The minimum crude protein (35.09 %) was recorded in absolute control.

The application of nano-sized nutrients, including nano nitrogen, nano sulphur, and nano zinc as a foliar spray, can significantly enhance the crude protein and oil content in sunflower seeds. Several factors contribute to this improvement as mentioned by Bhosale *et al.* (2011). Firstly, nano-sized nutrients are more easily absorbed by sunflower plants through their leaves, leading to efficient nutrient uptake as outlined by Kadasiddappa *et al.* (2013). This increased availability of

Table 46. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on quality parameters of sunflower

Quality parameters of sunflower							
Treatments	Details	Crude Protein (%)			Oil Content (%)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	19.06	18.88	18.94	35.27	34.92	35.09
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	20.44	20.31	20.38	37.81	37.58	37.69
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	21.13	20.94	21.00	39.08	38.73	38.91
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.31	22.19	22.25	39.43	39.08	39.25
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	21.69	21.50	21.56	40.35	40.12	40.24
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.94	22.69	22.81	40.58	40.12	40.35
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	21.81	21.69	21.75	41.74	41.39	41.57
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	22.81	22.56	22.69	42.20	41.74	41.97
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	21.31	21.13	21.19	39.89	39.54	39.72
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	22.19	21.88	22.06	40.12	39.78	39.95
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	21.56	21.38	21.44	41.05	40.47	40.76
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	22.56	22.38	22.50	41.28	41.05	41.16
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	21.94	21.69	21.81	42.43	41.97	42.20
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	23.13	22.94	23.06	42.78	42.43	42.61
	S.Em ±	0.61	0.61	0.61	1.13	1.12	1.13
	CD @ 5%	1.78	1.77	1.78	3.30	3.27	3.28

nitrogen, sulphur, and zinc, which are crucial for seed development, plays a pivotal role Raja *et al.*, 2020. Maintaining a balanced nutrient ratio is essential for proper seed development, and the simultaneous application of these nano nutrients helps ensure the right proportions of these essential elements for optimal seed protein and oil synthesis as stated by Deshmukh *et al.* (2020).

Additionally, nitrogen and zinc are important components of chlorophyll and other photosynthetic chemicals, which improves photosynthesis and provides more energy and carbon for protein and oil production within the seeds as put forth by Rasool *et al.* (2013). Furthermore, these nutrients boost enzymatic activity, which is necessary for a variety of metabolic activities, including the conversion of nutrition into proteins and lipids as stated by Gokhale *et al.* (2019). Protein synthesis is stimulated by adequate nitrogen and sulphur levels, whereas zinc stimulates oil formation in the seeds. These nano-sized nutrients are transported and translocated efficiently throughout the plant, ensuring that they reach the growing seeds on time as depicted by Kundu *et al.* (2017). Furthermore, the benefits of foliar application, as well as reduced stress effects, improved nutrient distribution, and greater nutrient mobility within the plant, all collectively contribute to the enhanced protein and oil content in sunflower seeds as outlined by Singh and Kumar (2017), Gangadhara *et al.* (2018) and Krishnamurthy and Mathan (2018).

4.10 Effect of different levels of nano nitrogen, sulphur and zinc on economics of production of sunflower

The data on gross monetary return (GMR), net monetary return (NMR) and B: C ratio are presented in Table 46.

4.10.1 Gross monetary returns (₹ ha⁻¹)

Data on gross monetary return (GMR) as influenced by different treatments are presented in Table 47. There was significant ($p < 0.05$) influence on net monetary return due to the application of different levels of nano nitrogen, sulphur and zinc foliar spray. The significantly ($p < 0.05$) highest gross monetary return ₹ 150655 ha⁻¹ was obtained with the application 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄). This treatment was found significantly ($p < 0.05$) superior over rest of the treatments and on par with T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (₹ 145870 ha⁻¹). These results we in line with Dambale *et al.* (2018) and Sarvari *et al.* (2019)

4.10.2 Net monetary returns (₹ ha⁻¹)

Data on net monetary return (NMR) as influenced by different treatments is presented in Table 47. There was significant ($p < 0.05$) influence on net monetary return due to the application of different treatments. The significantly ($p < 0.05$) highest net return (₹ 98420 ha⁻¹) was obtained with the application 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm + nZn @ 500ppm (T₁₄) which was found significantly ($p < 0.05$) superior over T₂ (₹ 78324 ha⁻¹) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). these results were similar with Yadav *et al.* (2021).

4.10.3 B: C ratio

Data on B: C ratio as influenced by different treatments are presented in Table 47. There was significant ($p < 0.05$) influence on net monetary return due to the application of different levels of nano nitrogen, sulphur and zinc foliar spray. The significantly ($p < 0.05$) highest B: C ratio ₹ 150655 ha⁻¹ was obtained with the application T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @ 250ppm) (3.03) compare to T₂ (2.98) which had Package of practice (FYM + Bio fertilizers + NPK + Zn + B). The results were in concurrent with Sarvari *et al.* (2019) and Ajithkumar *et al.* (2021).

4.11.1 Practical utility of the experiment

- **Mitigation of soil acidity:** Reduced nitrogenous fertilizer and zinc sulphate in acidic soil enhances nutrient supply and soil acidity, promoting sunflower growth and soil microorganism function.
- **Precise application, targeted nutrient delivery and resource efficiency:** Nano-fertilizers enhance sunflower plant growth by providing precise nutrients, reducing labor and frequency of use, thus minimizing input costs and environmental impact.
- **Cost-Effectiveness:** Reduced soil fertilizer can significantly reduce farming costs while maintaining or enhancing sunflower yields, aligning with sustainable and cost-effective farming methods.

- **Soil health enhancement:** Nano fertilizers can improve soil health by reducing the application of fertilizers, addressing deficiencies in acidic soils and promoting better nutrient uptake for plant growth.

4.11.2 Future line of work

The future line of work for implementing nano-fertilizers in sunflower production in acidic soil involves several potential directions:

- **Nano-fertilizer Formulation Optimization:** Researchers are working on enhancing nano-fertilizer formulations for sunflowers in acidic soil by adjusting nutrient ratios and particle sizes for optimal absorption and utilization.
- **Soil-Plant Interaction Studies:** Studying the molecular interaction between nano-fertilizers and acidic soil is crucial for understanding their effects on soil pH, nutrient availability, and plant growth.
- **Long-Term Impact Assessment:** Comprehensive studies on the long-term effects of nano-fertilizer use in acidic soil are crucial, assessing immediate crop performance, sustained impact on soil health, microbial communities, and environmental factors.
- **Economic Viability Studies:** The practical implementation of nano-fertilizers in acidic soil sunflower cultivation requires a cost-benefit analysis, considering production costs, yield increases, and environmental benefits.

SUMMARY

V SUMMARY

The Research entitled “**Effect of different levels of Nano nitrogen, sulphur and zinc on soil properties, nutrient dynamics and productivity of sunflower in acidic soil**” was undertaken during *kharif* 2021 and 2022. In this study, a field trail was conducted in the plot at ZARS, UASB, GKVK, Bengaluru-65. The observations documented in this study are summarized in the following.

Application of different levels of nitrogen and zinc sulphate fertilizer to soil and nano nitrogen, sulphur and zinc fertilizer as foliar spray had a significant influence on nutrients dynamics, nutrients uptake, growth, yield, quality and economics of production of sunflower in acidic soil.

5.1 Effect of different levels of Nano nitrogen, sulphur and zinc on soil properties

The soil physical characters were non-significantly different by the application of different levels of nitrogen and zinc sulphate fertilizer to soil. Between the various treatments, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded numerically lower bulk density (1.33 Mg m⁻³) and higher water holding capacity (33.65%) over the rest of the other treatments.

The chemical characteristics of soil, non-significantly enhanced by addition of different levels of nitrogen and zinc sulphate fertilizer to soil. Numerically, lower soil pH (5.51), higher EC (0.17 dS m⁻¹) were documented in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and in case of organic carbon (0.58 %) treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded higher compare to different combination of fertilizers treatments and absolute control.

Available soil nutrients like Nitrogen, Sulphur and Zinc content differed significantly due to application of different levels of nitrogen and zinc sulphate fertilizer to soil. 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 T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B). 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.

Soil biological properties like microbial biomass carbon and nitrogen, dehydrogenase activity and acid phosphatase activity did not vary significantly. However, with the application of in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) numerically higher microbial biomass carbon and nitrogen (304.53 and 60.91 µg g⁻¹ soil) was recorded and with the application of treatment T₉ (25% RDN + nU @ 2 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) (75.53 µg TPF g⁻¹ 24hr⁻¹) dehydrogenase activity found numerically higher. On the other hand, with treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) urease activity (22.42 µg NH₄-N g⁻¹ hr⁻¹) was found to be significant among the treatment and acid phosphatase activity (33.70 µg PNP g⁻¹ hr⁻¹) was non-significant.

5.2 Effect of different levels of Nano nitrogen, sulphur and zinc on Nutrients dynamics

Among all the treatments, treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) recorded significantly higher easily plant available fractions of nitrogen (Nitrate, Nitrite and ammonical N), sulphur (Water soluble, extractable and Inorganic S) and zinc (water soluble, exchangeable and organic matter bound Zn). On the other hand, unavailable fractions of nitrogen, sulphur and zinc did not vary significantly at different intervals like 30DAS, 60DAS and at harvest of sunflower.

Nitrogen fractions like Nitrate (7.33, 6.81 and 6.56 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively), Nitrite (52.50, 48.79 and 47.00 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) and ammonical (150.46, 138.04 and 131.21 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) nitrogen recorded significantly higher in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) compare to other treatments combination.

Sulphur fractions like Water soluble (8.63, 7.95 and 7.50 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively), extractable (6.56, 5.91 and 5.52 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) and inorganic (38.23, 36.32 and 35.23 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) sulphur recorded significantly higher in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) compare to other treatments combination and lower was recorded in absolute control.

Zinc fractions like water soluble + exchangeable (1.39, 1.28 and 1.21 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) and organic matter bound (2.53, 2.34 and

2.25 mg kg⁻¹ at 30DAS, 60DAS and at harvest of sunflower, respectively) zinc recorded significantly higher in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) compare to other treatments combination and followed by the treatments applied with 50% zinc sulphate and then by 25% zinc sulphate to soil.

5.3 Effect of different levels of Nano nitrogen, sulphur and zinc on nutrients concentration, nutrients uptake and nutrients use efficiency

Significantly higher N (3.69 and 0.90 % in seed and stalk, respectively), S (0.53 and 0.23 % in seed and stalk, respectively) and Zn (30.85 and 109.16 mg kg⁻¹ in seed and stalk, respectively) concentration in sunflower was recorded in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm). Significantly lower N, P and K concentration was found in absolute control and all other nutrients concentration in seeds and stalk did not had a significant difference with different combination of treatments.

Higher total uptake of major nutrients like nitrogen (132.23 kg ha⁻¹) phosphorous (35.10 kg ha⁻¹) and potassium (88.58 kg ha⁻¹), secondary nutrients like calcium (28.75 kg ha⁻¹) magnesium (19.06 kg ha⁻¹) and sulphur (23.52 kg ha⁻¹) and micronutrients like B (317.75 g ha⁻¹), Fe (1596.29 g ha⁻¹), Mn (280.76 g ha⁻¹), Zn (572.78 g ha⁻¹) and Cu (75.34 g ha⁻¹) by sunflower was observed in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) when compare to treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Lower uptake of these nutrients was observed in absolute control (T₁) where no external source of nutrients was applied. This increased uptake of macro and micro nutrients is due to higher seed and stalk yield in that treatment (T₁₄).

Higher Nitrogen use efficiency was observed with the application of 25% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm (T₁₀) recorded 72.01 kg kg⁻¹. On the other hand, Phosphorus (P) and Potassium (K) use efficiency, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded higher nutrient use efficiency (26.47 and 35.29 kg kg⁻¹ Phosphorus and Potassium use efficiency, respectively) compare to treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B).

5.4 Effect of different levels of Nano nitrogen, sulphur and zinc on growth, yield and quality and economics of production of sunflower

In the field experiment, growth parameters like plant height (28.89, number of green leaves, in sunflower plant were significantly higher at 30 DAS with the application of treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm), 60 and at harvest stage in the treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) over treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B).

With respect to yield parameters like filled seeds (942), percent chaffiness (7.09 %), dry matter production (148.02 148.02 g plant⁻¹), seed yield (2510.91 kg ha⁻¹) and stalk yield (4537.47 kg ha⁻¹) recorded significant with application of treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) and in case of number of unfilled seeds (109) significantly higher was recorded in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Quality parameters like crude protein (23.03 %) and oil content (42.61 %) was significantly influenced with application of treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) compared to control. The monitory benefits from sunflower varied significantly with all combination of treatments, the gross returns (₹ 150655 ha⁻¹) and net returns (₹ 98420 ha⁻¹) are higher in treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) and the treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) had the greater benefit cost ratio (3.03) compared to all other treatments.

5.5 Conclusion:

The study that was carried out to examine the effect of different levels of Nano nitrogen, sulphur, and zinc on soil properties, nutrient dynamics, and productivity of sunflower in acidic soil has favorable results. With regard to different soil properties, nutrient uptake, nutrients use efficiency, nutrients dynamics, and sunflower growth and yield across all treatment combinations, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) had the best performance. However, when considering the economics of sunflower production, treatment T₈ (75% RDN + nU @ 4 ml/l + 50% ZnSO₄ + nS @ 100ppm + nZn @250ppm) performed better overall. It demonstrated that the application of nano fertilizers has resulted in improved sunflower performance by improving soil characteristics and boosting soil fertility and production.

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VI REFERENCES

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APPENDICES

APPENDIX-I

Physical and chemical properties of FYM

Parameters	Values
Bulk density (Mg m^{-3})	1.12
MWHC (%)	48.32
Colour	Dark grey
pH (1:10)	5.92
EC (dS m^{-1})	2.35
Organic carbon (%)	32.80
Total Nitrogen (%)	0.60
Total Phosphorus (%)	0.31
Total Potassium (%)	0.57
Total Calcium (%)	0.78
Total Magnesium (%)	0.21
Sulphur (mg kg^{-1})	25.60
Iron (mg kg^{-1})	973.0
Manganese (mg kg^{-1})	456.0
Zinc (mg kg^{-1})	164.0
Copper (mg kg^{-1})	66.80

APPENDIX-II

Cost of cultivation of sunflower (Details of All Treatment)

Sr.no.	Particulars	Cost(Price*Unit)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
1	Ploughing	1500*2	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
2	Harrowing	1000*1	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
3	Stubble collection	250*3W	750	750	750	750	750	750	750	750	750	750	750	750	750	750
4	Fertilizer application	250*3W		750	750	750	750	750	750	750	750	750	750	750	750	750
5	Sowing	300*3M + 250*4W	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
6	Gap filling and thinning	300*1M + 250*2W	800	800	800	800	800	800	800	800	800	800	800	800	800	800
7	Weeding	250*4W	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
8	Irrigation	300*2M	600	600	600	600	600	600	600	600	600	600	600	600	600	600
9	Earthing Up	300*2M + 250*3W	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
10	Spraying	300*2M*3S			1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800	1800

∴

11	Cost of seed	300*5kg	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
12	FYM	3000*6.25t		18750	18750	18750	18750	18750	18750	18750	18750	18750	18750	18750	18750	18750
13	Urea	8/kg*37.5		300	75	75	150	150	225	225	75	75	150	150	225	225
14	SSP	37/kg*50		1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850	1850
15	MOP	23/kg*37.5		863	863	863	863	863	863	863	863	863	863	863	863	863
16	Nano-N	240/500ml			1536	3072	1536	3072	1536	3072	1536	3072	1536	3072	1536	3072
17	Nano-S	1500/100g			2400	2400	2400	2400	2400	2400	4800	4800	4800	4800	4800	4800
18	Nano-Zn	100/100g			2000	2000	2000	2000	2000	2000	4000	4000	4000	4000	4000	4000
19	ZnSO4	10kg		1200	600	600	600	600	600	600	300	300	300	300	300	300
20	Borax	15kg		1275	1275	1275	1275	1275	1275	1275	1275	1275	1275	1275	1275	1275
21	Azatobactor	375g		250	250	250	250	250	250	250	250	250	250	250	250	250
22	Harvesting and threshing	300*3M + 250*4W	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
23	others		500	500	500	500	500	500	500	500	500	500	500	500	500	500
			34750	39538	46449	47985	46524	48060	46599	48135	50549	52085	50624	52160	50699	52235

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Effect of different levels of nano nitrogen, sulphur and zinc on soil physico-chemical properties, growth and productivity of sunflower in an acidic soil

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Abstract:

A field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during *Kharif* season during 2021 and 2022 to study the effect of different levels of nano nitrogen, sulphur and zinc on soil physico-chemical properties, growth and productivity of sunflower in an acidic soil. The soil was sandy loam (Alfisol) in texture and experiment was laid out in randomized block design with 3 replications and comprised of 14 treatments. Results revealed that the application of different levels of nitrogen and zinc sulphate fertilizer to soil, did not significantly affect its physical or chemical characteristics. The available soil nutrients like nitrogen (307.25 kg ha⁻¹), sulphur (13.28 mg kg⁻¹) and zinc (1.23 mg kg⁻¹) differed significantly, with treatment of T₂ (Package of practice (FYM + Bio fertilizers + NPK + Zn + B)). However, all other major, secondary, and micro nutrients did not vary significantly. Similarly, treatment T₁₄ significantly improved sunflower plant growth parameters, including plant height and green leaf count and yield parameters like seed yield (2510.91 kg ha⁻¹) and stalk yield (4537.47 kg ha⁻¹) in the acidic soil compared to treatment T₂.

Keywords: nano-fertilizer, soil properties, sunflower, productivity, acidic soil

INTRODUCTION:

Indian population recorded 683 million in the year of 1981 but it is estimated that by 2030, it will attain to 1475 million. To feed the projected population of 1.48 billion by 2030, India needs to produce 350 million tonnes of food grains. This upward trend indicated that development and use of new types of fertilizers are one of the few practical options for feeding projected global population of 9.6 billion in 2050 or more, the ecosystems and the environment (Raliya and Singh, 2016). Therefore, it is imperative to identify and apply available innovative technologies in fertilizer research and development. Fertilizer is a critical input needed for increasing production of food grains and other agricultural commodities within the overall constraints of extremely limited scope for increasing land area under cultivation. The adoption of modern technology incorporating use of HYV seeds, irrigation and fertilizers in the late 60s provided the impetus for increasing production of food grains at an accelerated pace.

Over the last 35 years, additional nutrients applied as manufactured fertilizers have been responsible for 50-55 per cent of the yield increase in developing countries including India. Though the consumption of chemical fertilizers is increasing steadily over the years, the use efficiency of nutrients applied through fertilizers continues to remain low, for N (30-40%), P

(15-20%), K (50-55%), and micronutrients (2-5%), owing to nutrient losses from soils or conversion of nutrients into slowly cycling / recalcitrant pools within the soils (Jyothi and Hebsur, 2017). In India, fertilizer use efficiency is declining over the years. The greatest concern is to make increased fertilizer use more sustainable, attractive and profitable to the farmer. Attempts have been made all over the world to increase the fertilizer use efficiency, but not much headway has been achieved. In this context, there would be greater importance of the information on how to increase the nutrient use efficiency of fertilizers by the application of nanotechnology in the coming years. Liu *et al.* (2022) narrated that amongst the numerous applications of nanotechnology in soil science use of nano-fertilizer is the emerging field to study upon.

Nano-fertilizer may be defined as the nano particles, which can supply essential nutrients for plant growth, have higher use efficiency and can be delivered in a timely manner to arhizospheric target or by foliar spray (Helaly *et al.*, 2014). Nano particles have extensive surface area and capable of holding abundance of nutrients and release it slowly and steadily such that it facilitates uptake of nutrients matching the crop requirement without any associated ill- effects of customized fertilizer inputs. Soil health has been defined as the capacity of soil to function as a living system, with ecosystem and land use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health. soil health is dependent on the maintenance of four major functions: carbon transformations; nutrient cycles; soil structure maintenance; and the regulation of pests and diseases.

Oilseeds play an important role in agricultural economy of India. Oilseeds are important next only to food grains in terms of area, production and value. The production of oilseeds in India is below the target levels. Among oilseed crops, sunflower (*Helianthus annuus* L.) is an important annual oilseed crop, belonging to the family *Asteraceae*. Sunflower ranks third, next to groundnut and soybean in terms of total production of oilseeds in the world. In India, sunflower was cultivated on an area of about 0.29 million hectares with an annual production of 0.21 m t and productivity of 738 kg ha⁻¹ (Anon., 2011). Even though the sunflower crop has the yield potential of around 1.5 t ha⁻¹ under favorable conditions, the average productivity level in India is only 0.7 t ha⁻¹. The main reasons for low productivity of sunflower is poor seedling vigor, poor seed setting and high per cent of chaffy seeds in the centre of the capitulum. Reddy *et al.* (2012) opined that, inadequate and imbalanced nutrient supply is the reason for low productivity of sunflower. In recent years, micronutrient deficiencies and their impact on crop yields are widely reported in various parts of the country (Anon., 2011).

Nitrogen is important in fuelling growth and providing high yields. It is largely needed during leaf formation and to ensure optimal photosynthate production in the leaves. Nitrogen fed at an early stage of crop development will help build the overall size of the leaf canopy (Shen *et al.*, 2015). During the later stages of growth, nitrogen use helps to maintain the greenness of the canopy and maximize the yield. Sulphur is one of the essential elements and is important to the plants for protein and oil synthesis and it is constituent of amino acids like cystine, cysteine and methionine. Functionally, sulphur significantly influences the yield and quality of oilseed crops, improves odour and flavors and imparts resistance to cold and hence

it is generally considered a “quality nutrient”. However, the deficiency of sulphur is known to decrease the yield as well as quality, especially when soils are deficient. Apart from major nutrients, micronutrients also play a vital role in sunflower production. Zinc play an important role in physiology of sunflower crop and is a part of enzyme system or catalyst in enzymatic reactions (De Rosa *et al.*, 2010). They are required for plant activities such as respiration, meristematic development, chlorophyll formation, photosynthesis, energy system, protein and oil synthesis, tannin and phenolic compounds development. In this backdrop a field experiment was conducted to evaluate the effect of different levels of nano nitrogen, sulphur and zinc on soil physico-chemical properties, growth and productivity of sunflower in acidic soil.

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, P₂O₅, K₂O (major nutrient), S (secondary nutrient), Zn (micro nutrient) using standard protocols and the data obtained are presented in Table 1.

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

Parameters	Value		Methods	References
pH	5.81	5.84	Potentiometry	Jackson (1973)
EC (dS m ⁻¹)	0.11	0.12	Conductometry	Jackson (1973)
MWHC (%)	1.39	1.38	Keen’s cup method	Piper (1966)
Bulk density (g/cc)	30.59	30.92		
Organic carbon (%)	0.49	0.50	Wet oxidation	Walkley and Black (1934)
Available nitrogen (kg ha ⁻¹)	280.59	306.96	Alkaline potassium permanganate and Kjeldhal distillation method	Subbiah and Asija (1956)
Available phosphorus (kg ha ⁻¹)	22.29	26.71	Diacid digestion and vanadomolybdate method	Jackson (1973)
Available potassium (kg ha ⁻¹)	154.90	159.69	Neutral normal ammonium acetate extraction and flame photometer method	Jackson (1973)
Available sulphur (mg kg ⁻¹)	10.16	11.56	0.15 % CaCl ₂ extraction and turbidity method	Black (1965)
Zinc (mg kg ⁻¹)	0.72	0.90	DTPA extraction and atomic Absorption spectrophotometry	Lindsay and Norvell (1978)

Experimental details: A field experiment was conducted at Zonal Agricultural Research Station, GKVK, Bengaluru during *Kharif* season in 2021 and 2022. 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 ZnSO₄ + 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.

Treatment details:

Treatments	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: Physical soil properties like bulk density, particle density, maximum water holding capacity and chemical soil properties pH, electrical conductivity (dS/m), organic carbon (%) and nutrients status of N, P₂O₅, K₂O (major nutrient), S (secondary nutrient), Zn (micro nutrient).

Growth and Yield parameters Observations: Growth parameters like plant height (cm), number of leaves per plant has been recorded at 30DAS, 60DAS and at harvest of the sunflower and seed and stalk yield has been recorded after harvest of the sunflower crop.

Statistical analysis of Data: The experimental data collected for 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 was 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 physico-chemical properties:

The soil physical characters (Table. 2) did not vary by the application of different levels of nitrogen and zinc sulphate fertilizer to soil. Between the various treatments, treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded numerically lower bulk density (1.33 Mg m⁻³) and higher water holding capacity (33.65%) over the rest of the other treatments.

There was a notable numerical decrease (Non significant) in bulk density and increase water holding capacity was recorded. soil organic matter (SOM) is less dense than mineral soil particles, leading to a numerical decrease in bulk density. Nitrogen fertilizers stimulate plant and microbe growth, which adds organic matter to the soil. SOM is good at holding water due to its large surface area and affinity for water molecules. Improved aggregation of soil particles can decrease bulk density (Raliya and Singh, 2016). Nitrogen fertilizers can also increase root biomass, which loosens soil and reduces bulk density. Higher levels of fertilizer application can have a more pronounced effect on soil bulk density and water-holding capacity (Jyothi and Hebsur, 2017). However, excessive nitrogen fertilization can have negative consequences for soil health, such as increased nitrate leaching and nitrous oxide emissions. Therefore, it is crucial to apply nitrogen fertilizers at recommended rates and in conjunction with other soil management practices. Similar were outlined by Kim *et al.* (2013).

The chemical characteristics (Table. 3) of soil, it was non-significant by addition of different levels of nitrogen and zinc sulphate fertilizer to soil. Numerically, lower soil pH (5.51), higher EC (0.17 dS m⁻¹) were documented in treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and in case of organic carbon (0.58 %) treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) recorded higher compare to different combination of fertilizers treatments and absolute control.

The application of nano nitrogen, sulphur, and zinc to soil did not significantly affect its chemical properties like pH, electrical conductivity, and organic carbon as noted by Raliya *et al.* (2015). However, there was a notable (non-significant) decrease in soil pH and an increase in electrical conductivity and organic carbon. Nitrogen fertilizers are acidic, releasing hydrogen ions into the soil, which can lead to soil acidification (Efthymiadis, 2017). They also increase electrical conductivity by adding salts to the soil, which can conduct electricity (Wanyika, 2012). Nitrogen fertilizers can increase organic carbon (OC) by promoting plant growth, which absorbs nitrogen and converts organic matter into organic carbon as given by Moshe *et al.* (2012). The effects of these fertilizers on soil pH, EC, and OC vary depending on the soil type,

Table 2. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Bulk Density (Mg m^{-3}) and Maximum Water Holding Capacity (%) after the harvest of sunflower.

Treatments	Details	Bulk Density (Mg m^{-3})			Maximum Water Holding Capacity (%)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	1.38	1.37	1.38	30.32	30.49	30.41
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	1.34	1.33	1.34	32.51	32.69	32.60
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.37	1.35	1.36	31.04	31.28	31.16
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.37	1.36	1.36	31.26	31.31	31.29
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	32.32	32.41	32.37
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	32.98	33.15	33.07
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.35	1.34	1.34	32.64	32.85	32.75
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	1.34	1.33	1.33	33.60	33.65	33.63
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	1.36	1.36	1.36	31.35	31.51	31.43
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	1.35	1.34	1.34	32.67	32.89	32.78
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	1.36	1.35	1.35	32.01	32.24	32.13
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	1.35	1.34	1.34	32.78	32.99	32.89
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	1.34	1.32	1.33	33.10	33.20	33.15
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm+ nZn @500ppm	1.33	1.33	1.33	33.60	33.70	33.65
	S.Em $\pm$	0.04	0.04	0.04	0.91	0.91	0.91
	CD @ 5%	NS	NS	NS	NS	NS	NS

Table 3. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on pH, Electrical Conductivity (dS m⁻¹) and Organic carbon (%) status of soil after the harvest of sunflower

[illegible]

the amount of fertilizer applied, and other factors. It is crucial to use these fertilizers in moderation and regularly test the soil to monitor their effects on soil chemistry as indicated by Helaly *et al.* (2014).

Available soil nutrients like Nitrogen, Sulphur and Zinc content differed significantly due to application of different levels of nitrogen and zinc sulphate fertilizer to soil (Table. 4 and 5). The available nitrogen ($307.25 \text{ kg ha}^{-1}$), 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} ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$). Significantly low nitrogen, sulphur and zinc were observed in absolute control compare to all other treatment. In contrast, all other major, secondary and micro nutrients of soil 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). 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). Moreover, 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 Manikanta *et al.* (2023) and Corradini *et al.* (2010).

Growth and yield parameters:

Figure 1 and 2 represents plant height (cm) and number of green leaves of sunflower as influenced by different levels of Nano fertilizer at different growth stages. With different treatments, plant height and number of green leaves varied significantly at all growth stages. Plant height gradually increased with crop age rise up to 60 DAS and subsequently a slightly lower increase until harvest. In the field experiment, growth parameters like plant height (28.89, number of green leaves, in sunflower plant were significantly higher at 30 DAS with the application of treatment T_8 ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 50\% \text{ ZnSO}_4 + \text{nS @ } 100\text{ppm} + \text{nZn @ } 250\text{ppm}$), 60 and at harvest stage in the treatment T_{14} ($75\% \text{ RDN} + \text{nU @ } 4 \text{ ml/l} + 25\% \text{ ZnSO}_4 + \text{nS @ } 200\text{ppm} + \text{nZn @ } 500\text{ppm}$) over treatment T_2 , which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B). Nano-sized nitrogen particles can improve plant growth by absorbing more easily through leaves, leading to better nutrient uptake and uniform distribution of nutrients. They also enhance the photosynthetic efficiency of plants, leading to greater energy production and leaf growth as marked by El-kady *et al.* (2010). Increased nitrogen availability in sunflowers can produce more chlorophyll, leading to healthier leaves and more numerous leaves. It also stimulates protein production, contributing to overall dry matter production as stated by Abdel-Salam *et al.* (2018).

Table 4. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on available major nutrient (Nitrogen, Phosphorus and Potassium) (kg ha⁻¹) status of soil after 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 5. Effect of different levels of Nano Nitrogen, Sulphur and Zinc on secondary and micro nutrients (Available Sulphur (mg kg⁻¹) and Zinc (mg kg⁻¹)) status of soil after the harvest of sunflower

Treatments	Details	Available Sulphur (mg kg ⁻¹)			Zinc (mg kg ⁻¹)		
		2021	2022	Pooled	2021	2022	Pooled
T ₁	Absolute control	5.99	7.37	6.68	0.58	0.73	0.65
T ₂	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	12.91	13.65	13.28	1.09	1.37	1.23
T ₃	25% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	11.09	13.27	12.18	0.89	1.12	1.00
T ₄	25% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.96	13.12	12.04	0.88	1.10	0.99
T ₅	50% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.71	12.82	11.76	0.87	1.09	0.98
T ₆	50% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.56	12.64	11.60	0.85	1.07	0.96
T ₇	75% RDN + nU @ 2 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.41	12.46	11.43	0.82	1.03	0.92
T ₈	75% RDN + nU @ 4 ml/l + 50% ZnSO ₄ + nS @ 100ppm + nZn @250ppm	10.35	12.39	11.37	0.81	1.02	0.91
T ₉	25% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	8.29	9.92	9.11	0.69	0.86	0.78
T ₁₀	25% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	8.15	9.75	8.95	0.67	0.84	0.75
T ₁₁	50% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	8.02	9.60	8.81	0.65	0.81	0.73
T ₁₂	50% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	7.87	9.42	8.64	0.62	0.78	0.70
T ₁₃	75% RDN + nU @ 2 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	7.55	9.04	8.29	0.61	0.76	0.69
T ₁₄	75% RDN + nU @ 4 ml/l + 25% ZnSO ₄ + nS @ 200ppm + nZn @500ppm	7.32	8.76	8.04	0.60	0.75	0.68
	S.Em ±	0.25	0.30	0.28	0.02	0.03	0.02
	CD @ 5%	0.74	0.87	0.81	0.06	0.08	0.07

Nano-sized nutrients can help plants cope with environmental stressors like drought, heat, or disease, allowing them to allocate more energy to growth. They can also regulate growth hormones, such as auxins and cytokinins, and reduce nitrogen loss when applied as a foliar spray. Additionally, nano-sized particles can interact positively with other nutrients, boosting plant growth parameters. However, the effectiveness of nano nitrogen as a foliar spray depends on factors like formulation, application timing, and local environmental conditions as mentioned by Pruthviraj *et al.* (2022) and Oad *et al.* (2018).

With respect to seed and stalk yield, Figure 3 represents the influence of different levels of nano nitrogen, sulphur and zinc on seed yield (2510.91 kg ha⁻¹) and stalk yield (4537.47 kg ha⁻¹) and it was recorded significant with application of treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm) compared to treatment T₂, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) which recorded seed yield (2510.91 kg ha⁻¹) and stalk yield (4537.47 kg ha⁻¹).

Nano-sized nutrients like nano nitrogen, nano sulphur, and nano zinc can improve seed filling, seed production, and stalk yield in sunflower plants. These nutrients are easily absorbed by the plant through the leaves, leading to enhanced nutrient absorption and improved seed filling and overall plant development as mentioned by Kiran and Samal (2021). They also promote various elements of plant growth, such as seed and stem production, photosynthesis, and nutrient absorption. The use of nano nutrients helps maintain an optimum nutritional balance, reducing deficits that may hinder growth. They also stimulate root health, resulting in increased nutrient absorption and overall plant vigor as stated by Dambale *et al.* (2018). Adequate nutritional levels, particularly micronutrients like zinc, can help sunflower deal with environmental stresses, promoting blooming and pollen viability. Foliar application ensures a steady supply of nutrients, allowing for more uniform and accurate nutrient delivery to different plant sections as noted by Tiwari *et al.* (2021). However, the effectiveness of these nano-sized nutrients depends on factors like product formulation, application timing, and local soil and environmental conditions. Careful monitoring and adherence to recommended application rates are essential to maximize benefits and prevent potential imbalances as given by Hegab *et al.* (2018).

CONCLUSION:

Nano-fertilizers can be effectively used in acidic soil and its effect on various soil properties are very minimal and can improve the growth and productivity of sunflower grown in acidic soil. Considering effects on soil properties and productivity of sunflower, treatment T₁₄ - 75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + nS @ 200ppm+ nZn @500ppm was found to have better performance as compared to package of practice. Nano-fertilizers can mitigate soil acidity, improve nutrient uptake and enhance sunflower growth. They offer precise application, reduced labour and improved yield. This approach is cost-effective and enhances soil health. It aligns with sustainable farming methods.

COLLABORATION WITH OTHER DEPARTMENTS /INSTITUTIONS:

- AICRP on Sunflower, ZARS, GKVK, Bengaluru.
- Department of Agronomy, College of Agriculture, GKVK, UAS, Bengaluru.

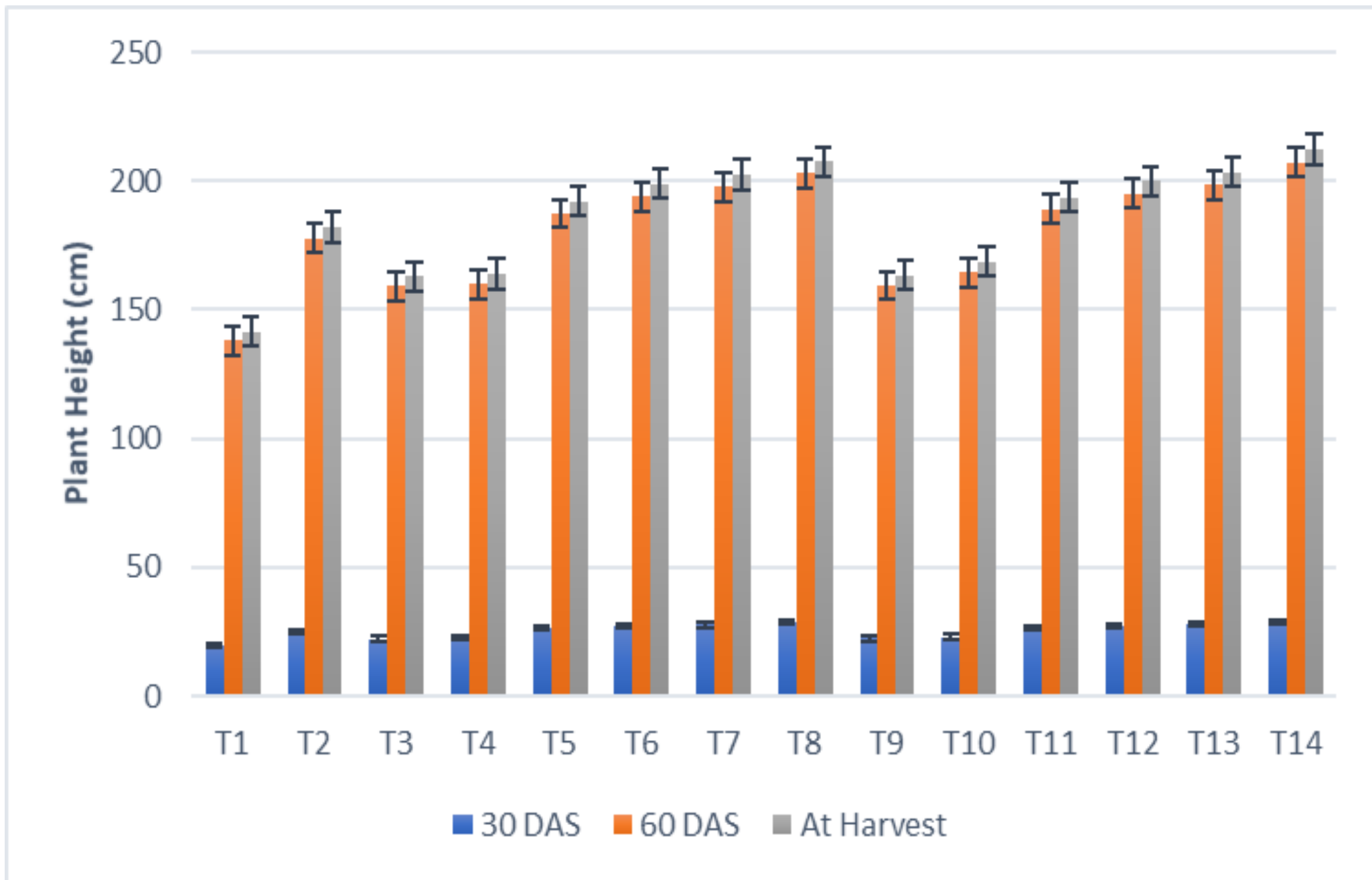


Figure 1: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on plant height (cm) at 30DAS, 60DAS and at harvest stages of sunflower

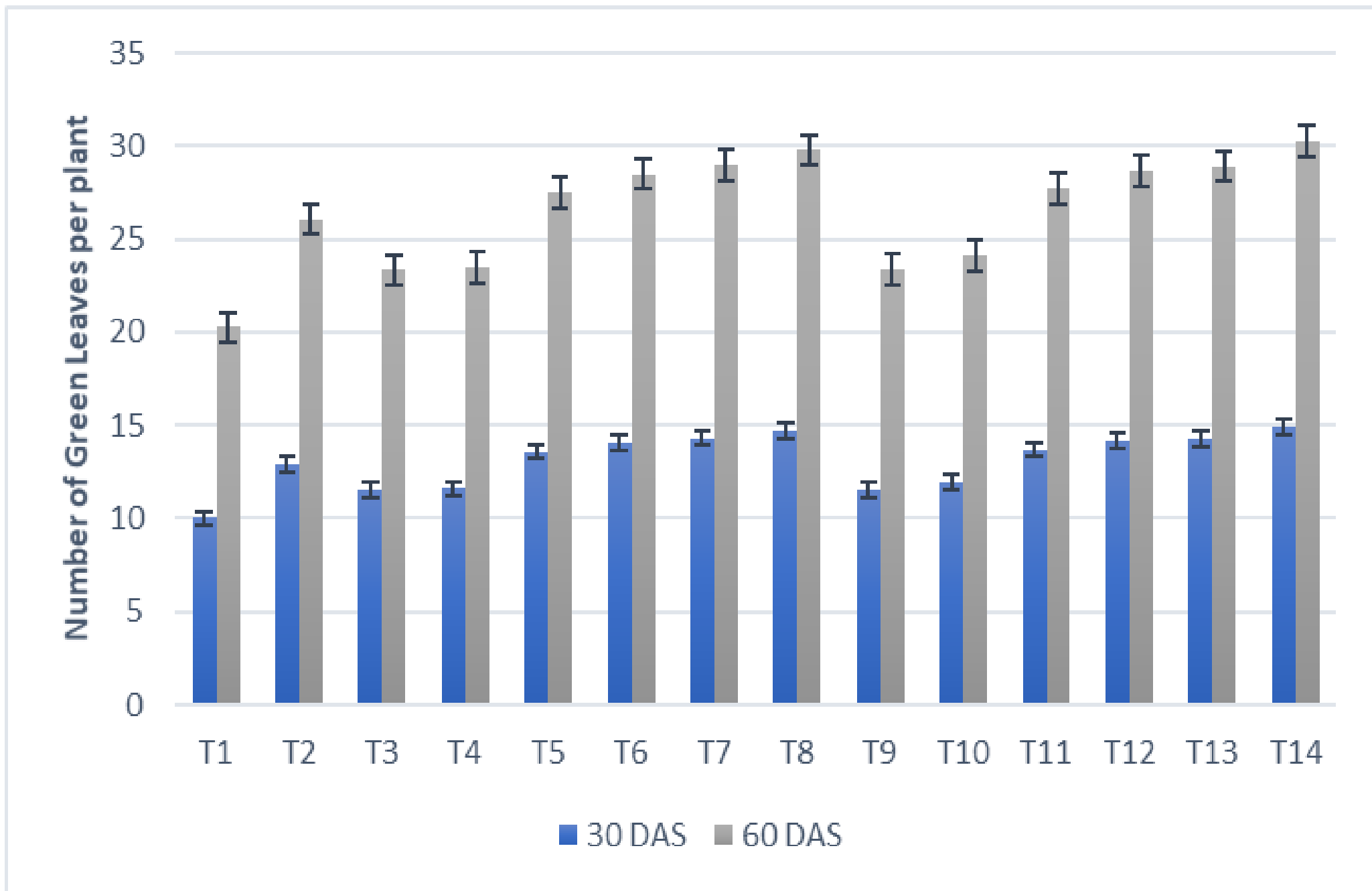


Figure 2: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on number of green leaves at 30DAS and 60DAS stages of sunflower

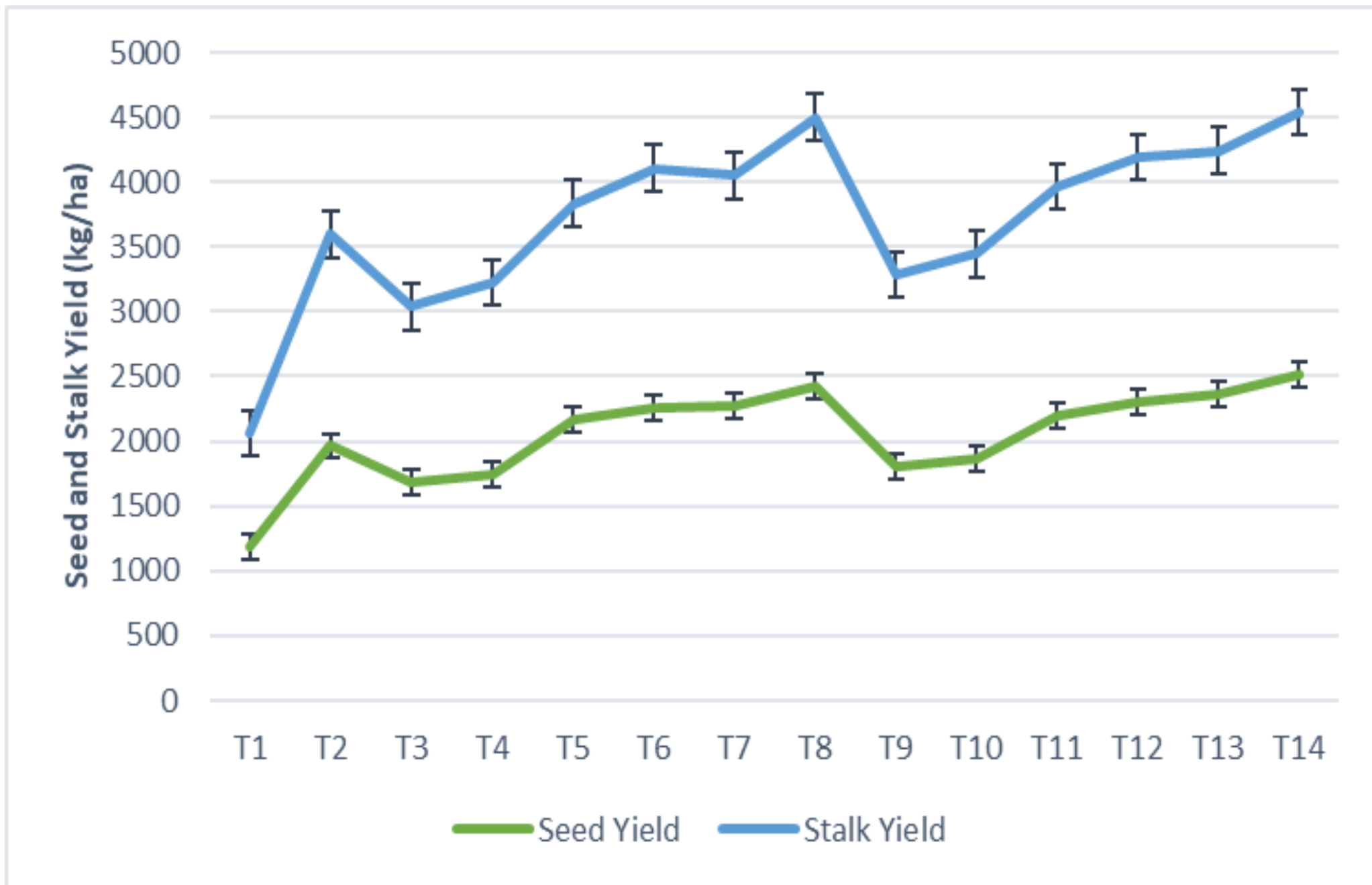


Figure 3: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Seed and Stalk yield (kg ha⁻¹) of sunflower

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Evaluating the Varied Impacts of Conventional Versus Nano Fertilizers on Soil Nutrient Levels, Utilization Efficiency and Biological Activity in Acidic Soil

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Authors' contributions

This work was carried out in collaboration among all authors. Authors RDS, MB, CS, SA, LBS and SRKM did conceptualization and designing of the research work and prepared the manuscript. Authors RDS and MB executed the field/lab experiments and did data collection, analysis and interpretation. All authors read and approved the final manuscript.

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ABSTRACT

A two-season field experiment was conducted at zonal agricultural research station, GKV, 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

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14 treatments. Results revealed that the available soil nutrients like nitrogen ($307.25 \text{ kg ha}^{-1}$), sulphur (13.28 mg kg^{-1}) and zinc (1.23 mg kg^{-1}) content differed significantly, with treatment T2 (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 with nano fertilizers than conventional one. Urease activity ($22.42 \mu\text{g NH}_4\text{-N g}^{-1} \text{ hr}^{-1}$) was found to be significantly higher in treatment T2 (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.

1. INTRODUCTION

Modern agriculture faces an ever-growing challenge to simultaneously meet the escalating global demand for food while ensuring environmental sustainability [1]. 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 [2]. 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 considerably impact nutrient availability and plant growth, necessitating a nuanced understanding of fertilizer interactions [3]. 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 [4]. 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 [3].

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 microbes and enzymes [1]. 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. [5]. 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.

2. MATERIALS 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

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

(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, GKV, 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 ZnSO₄ + 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.

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, P₂O₅, K₂O (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 [6]. 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 [7]. Available potassium was extracted with neutral normal ammonium acetate solution and was determined using flame-photometry as described by Page et al. [8].

The amount of Calcium and Magnesium in the soil sample was measured using Jackson [9] 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 BaCl₂ as stabilizing agent by Black [10]. 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 [11].

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:

$$\text{NUE (kg kg}^{-1}\text{)} = \frac{\text{Grain yield of fertilized plot (kg)} - \text{Grain yield of control plot (kg)}}{\text{Quantity of nutrient applied (kg)}}$$

Soil Biological Activity: The dehydrogenase activity in the soil samples was determined by mixing with CaCO₃ and TTC incubated at 37 °C for 24 hours, later, methanol was added and intensity of red colour was estimated in spectrophotometer as described by Casida et al. [12] 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°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 [13] and Expressed the urease activity as µg NH₄-N g⁻¹ hr⁻¹. Acid

Table 1. 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

Phosphatase activities were estimated by treating soil with toluene, universal buffer and PNP, later, extracted with CaCl₂ and NaOH and yellow colour intensity was estimated in spectrophotometer as per the procedure described by Eivazi and Tabatabai [13] 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 [14]. 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.

3. RESULTS AND DISCUSSION

3.1 Soil Nutrients Status after the Harvest of Sunflower

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 (Tables. 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 T₂, which had the

Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and it was on par with treatment T₁₄ (75% RDN + nU @ 4 ml/l + 25% ZnSO₄ + 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 microbes activity, leading to increased mineralization of organic matter, releasing nutrients into the soil as mentioned by Kottegoda et al. [15]. 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 [3]. 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. [5].

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 soil after 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 (c mol (p⁺) kg⁻¹) and available sulphur (mg kg⁻¹)) status of soil after 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

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 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 soil after 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+	7.70	8.24	7.97	0.62	0.78	0.70	4.35	4.62	4.48	0.23	0.26	0.25

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
	nZn @500ppm												
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

Table 6. Effect of different levels of nano nitrogen, sulphur and zinc on dehydrogenase acid phosphatase and urease ($\mu\text{g g}^{-1} \text{hr}^{-1}$) status of soil after the harvest of sunflower

Treatments	Details	Dehydrogenase ($\mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$)			Acid phosphatase ($\mu\text{g PNP g}^{-1} \text{hr}^{-1}$)			Urease ($\mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$)		
		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 $\pm$	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

3.2 Nutrients use Efficiency (NUE) of Sunflower

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 [16]. 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 [17]. 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. [18].

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 by Burmana et al. [19].

3.3 Soil Biological Activity after the Harvest of Sunflower

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 $75.53 \mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$ and the numerically highest in treatment T_9 (25% RDN + nU @ 2 ml/l + 25% ZnSO_4 + nS @ 200ppm+ nZn @500ppm) ($75.53 \mu\text{g TPF g}^{-1} 24\text{hr}^{-1}$) 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 ($33.70 \mu\text{g PNP g}^{-1} \text{hr}^{-1}$) 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 ($31.93 \mu\text{g PNP g}^{-1} \text{hr}^{-1}$).

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 ($22.42 \mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$) *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 $22.07 \mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$ that is on par with T_{13} , T_8 , T_7 , T_6 (21.47, 21.47, 21.22, $21.10 \mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$, respectively) and minimum nitrogen content in seed ($15.01 \mu\text{g NH}_4\text{-N g}^{-1} \text{hr}^{-1}$) 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. [5] and Collins et al. [20-22].

4. 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.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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