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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 Acidic Soil

D. S. ROHITHA[1], B. MAMATHA[2], A. SATHISH[3], S. CHANNAKESHAVA[4],
B. S. LALITHA[5] AND K. M. SRINIVAS REDDY[6]

[1,2,3&4]Department of Soil Science and Agricultural Chemistry, [5]Department of Agronomy, [6]Department of Entomology, College of Agriculture, UAS, GKVK, Bengaluru - 560 065
e-Mail : rohithds14@gmail.com

AUTHORS CONTRIBUTION

D. S. ROHITHA :
Conceptualization investigation, draft preparation and analysis;

B. MAMATHA :
Conceptualization framed research proposal and draft correction;

A. SATHISH ;
S. CHANNAKESHAVA ;
B. S. LALITHA &
K. M. SRINIVAS REDDY :
Conceptualization and manuscriptcorrection

Corresponding Author :
D. S. ROHITHA

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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 T_2 [Package of practice (FYM + Bio fertilizers + NPK + Zn + B)]. However, all other major, secondary, and micro nutrients did not vary significantly. Similarly, treatment T_{14} 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 T_2.

Keywords : Nano-fertilizer, Soil properties, Sunflower, Productivity, Acidic soil

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} (Annonymous, 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 (Anonymous, 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, P_2O_5, K_2O (major nutrient), S (secondary nutrient), Zn (micro nutrient) using standard protocols and the data obtained are presented in Table 1.

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 $ZnSO_4$ + 15 kg/ha Borax + 375 g/ha Azatobactor) was applied according to the treatment. The soil type was sandy loam (Alfisol) in texture and the experiment was laid out in randomized block design with 3 replications and comprised of 14 treatments. 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, P_2O_5, K_2O (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

TABLE 1

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)

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

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 T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + 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 findings were outlined by Kim *et al*. (2013).

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 ±	0.04	0.04	0.04	0.91	0.91	0.91
	CD @ 5%	NS	NS	NS	NS	NS	NS

The chemical characteristics (Table 3) of soil 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 T_2, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and in case of organic carbon (0.58%) treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + 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

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

Treatments	Details	pH			ElectricalConductivity (dS m^{-1})			Organic carbon (%)		
		2021	2022	Pooled	2021	2022	2021	Pooled	2022	Pooled
T_1	Absolute control	5.60	5.67	5.64	0.10	0.10	0.10	0.50	0.51	0.51
T_2	Package of practice (FYM + Bio fertilizers + NPK + Zn + B)	5.50	5.51	5.51	0.16	0.17	0.17	0.53	0.54	0.54
T_3	25% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.67	5.71	5.69	0.12	0.12	0.12	0.54	0.57	0.56
T_4	25% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.68	5.72	5.70	0.13	0.13	0.13	0.54	0.56	0.55
T_5	50% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.65	5.70	5.68	0.14	0.14	0.14	0.53	0.57	0.55
T_6	50% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.64	5.69	5.67	0.14	0.14	0.14	0.53	0.56	0.55
T_7	75% RDN + nU @ 2 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.63	5.68	5.66	0.15	0.16	0.15	0.53	0.55	0.54
T_8	75% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm	5.61	5.67	5.64	0.16	0.17	0.16	0.53	0.54	0.54
T_9	25% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm	5.80	5.81	5.81	0.12	0.12	0.12	0.56	0.58	0.57
T_{10}	25% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	5.77	5.78	5.78	0.11	0.12	0.11	0.55	0.56	0.56
T_{11}	50% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	5.77	5.80	5.79	0.14	0.14	0.14	0.56	0.58	0.57
T_{12}	50% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	5.72	5.76	5.74	0.14	0.14	0.14	0.55	0.58	0.57
T_{13}	75% RDN + nU @ 2 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	5.69	5.75	5.72	0.15	0.15	0.15	0.54	0.55	0.55
T_{14}	75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm+ nZn @500ppm	5.70	5.76	5.73	0.15	0.16	0.15	0.57	0.58	0.58
	S.Em ±	0.06	0.06	0.06	0.01	0.01	0.01	0.02	0.02	0.02
	CD @ 5%	NS	NS	NS	NS	NS	NS	NS	NS	NS

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, 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 kg ha^{-1}), available Sulphur (13.28 mg kg^{-1}) and zinc (1.23 mg kg^{-1}) recorded the highest in treatment T_2, which had the Package of practice (FYM + Bio fertilizers + NPK + Zn + B) and it was on par with treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm). Significantly low nitrogen, sulphur and zinc were observed in absolute control 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

Fig.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% RDN + nU @ 4 ml/l + 50% $ZnSO_4$ + nS @ 100ppm + nZn @250ppm), 60 and at harvest stage in the treatment T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm) 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). 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.

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	AvailableSulphur (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

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, Fig. 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 T_{14} (75% RDN + nU @ 4 ml/l + 25% $ZnSO_4$ + nS @ 200ppm + nZn @500ppm) compared to

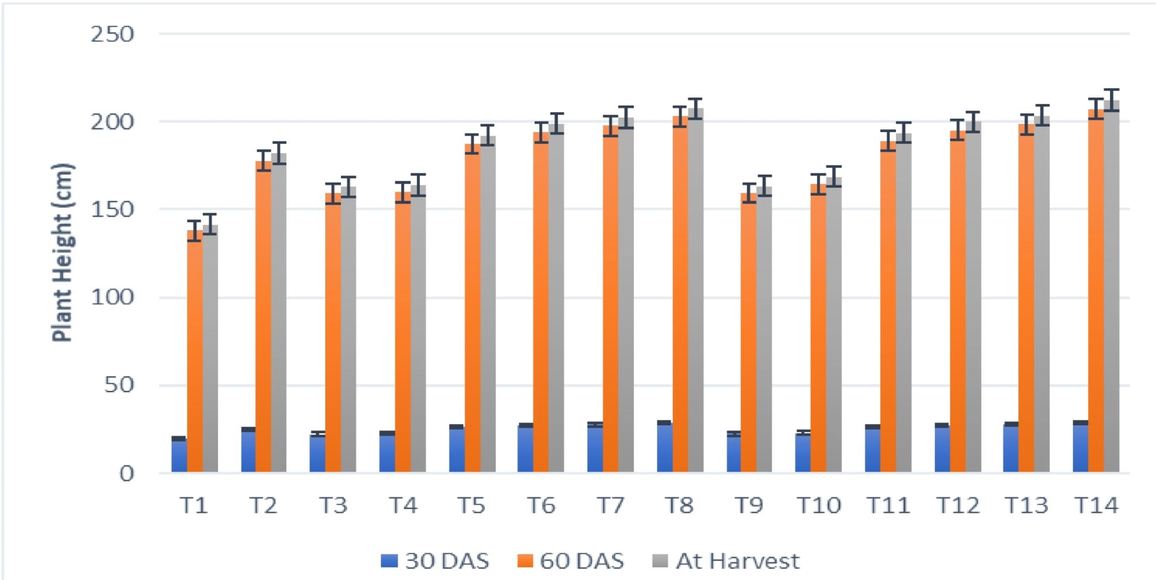

Fig. 1 : Effect of different levels of Nano Nitrogen, Sulphur and Zinc on plant height (cm) at 30DAS, 60DAS and at harvest stages of sunflower

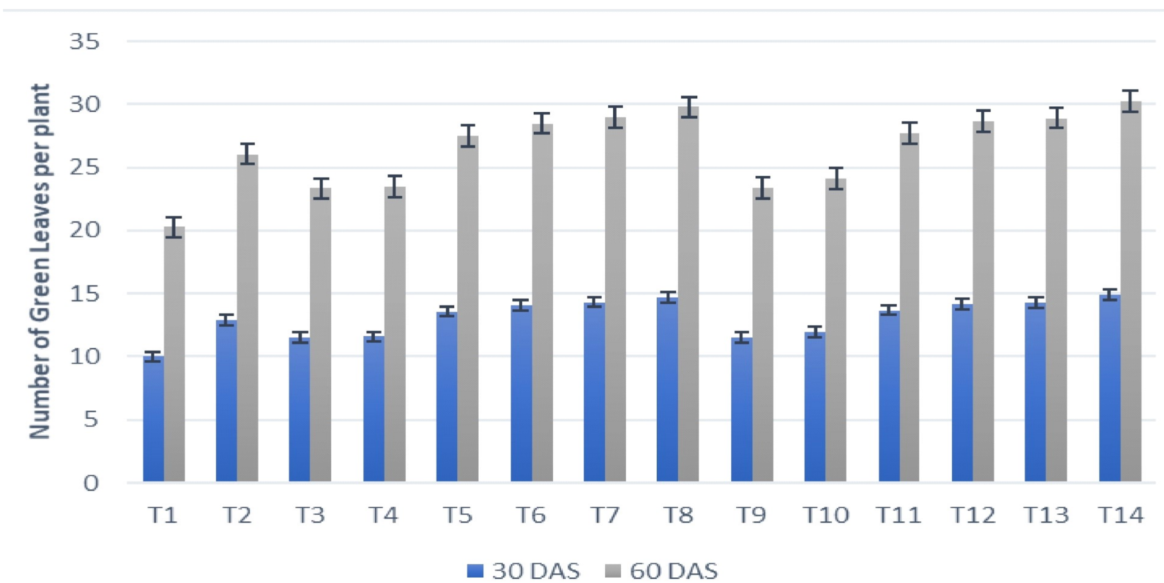

Fig. 2: Effect of different levels of Nano Nitrogen, Sulphur and Zinc on number of green leaves at 30DAS and 60DAS stages of sunflower

treatment T_2, 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

Fig. 3 : Effect of different levels of Nano Nitrogen, Sulphur and Zinc on Seed and Stalk yield (kg ha^{-1}) of sunflower

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).

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 T_{14} - 75 per cent RDN + nU @ 4 ml/l + 25 per cent $ZnSO_4$ + 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.

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